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DIMENSIONLESS GRAPHS OF FLOODS FROM RUPTURED DAMS.(U)
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RESEARCH NOTE NO. 8

DIMENSIONLESS GRAPHS OF FLOODS FROM RUPTURED DAMS

APRIL 1980

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Dams are subject to failure and the damages produced by the resulting flood are extensive. Alleviation or prevention of the damaging effects requires the knowledge of the flood characteristics. These include primarily the time of arrival of the flood-wave front, the maximum flood level and the time at which the maximum flood level occurs after dam failure.

Using a rational computation technique, based on the method of characteristics, dimensionless graphs of the aforementioned flood characteristics were prepared for a prismatic channel of general (Continued)

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parabolic cross section and several values of the parameters involved. These values were selected to cover the practical range of the field conditions affecting the magnitude of the dam-break flood. Results were obtained for such periods of time that the flood peak advanced adequately down-stream and either subsided or stabilized considerably.

DIMENSIONLESS GRAPHS OF FLOODS FROM RUPTURED DAMS

By
JOHN G. SAKKAS

Report prepared for
The Hydrologic Engineering Center
U.S. Army, Corps of Engineers
January 1974

THE AUTHOR
John G. Sakkas, Ph.D., Consulting Engineer, Davis, California.
Forward address: Public Power Corporation, Athens, Greece.

FOREWARD

The dimensionless curves presented in this report are intended for use in routing the dambreak flood down a dry prismatic channel. Three important properties of the flood wave may be determined: Time of arrival of the wave front, maximum flood depth, and time of maximum flood depth. The routing curves were prepared from the results of numerical simulation experiments which solved a dimensionless form of the St. Venant equations. The propagation of the flood wave tip along the dry valley floor was calculated, as well as propogation of the negative wave as it was reflected from the upstream boundary of the reservoir. It was possible to express the results in the form of dimensionless graphs because valley geometry was expressed as a simple, prismatic channel.

In utilizing these graphs, it is necessary to transform the irregular natural cross sections into one representative prismatic section. The important properties which must be preserved are storage and conveyance. Three basic forms of cross section shape are permitted: rectangular, triangular and parabolic. The equation for expressing the properties of each of these forms, as well as other equations necessary to utilize the dimensionless graphs, are presented in Annex I at the end of this volume.

This report culminates a line of research that started with the project "Numerical Techniques for Routing the Dam Break Flood on a Dry Bed" in which Drs. Theodor Strelkoff and John Sakkas developed a computer program for calculating the advance of a dam break flood in a dry prismatic channel. In a subsequent research project, "Flooding from Ruptured Dams," the same investigators extended their work to include a solution of the non-dimensional form of the St. Venant equation. This basic work was extended to produce the routing curves presented in this report. In view of the many uncertainties involved in routing the dam break flood, the fact that a reach of a river has to be transformed into a prismatic section is not an overwhelming simplification.

ABSTRACT

Dams are subject to failure and the damages produced by the resulting flood are extensive. Alleviation or prevention of the damaging effects requires the knowledge of the flood characteristics. These include primarily the time of arrival of the flood-wave front, the maximum flood level and the time at which the maximum flood level occurs after dam failure.

Using a rational computation technique, based on the method of characteristics, dimensionless graphs of the aforementioned flood characteristics were prepared for a prismatic channel of general parabolic cross section and several values of the parameters involved. These values were selected to cover the practical range of the field conditions affecting the magnitude of the dam-break flood. Results were obtained for such periods of time that the flood peak advanced adequately downstream and either subsided or stabilized considerably.

KEY WORDS: Dams; Floods; Graphs; Hydraulics; Rivers; Waves.

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DIMENSIONLESS GRAPHS OF FLOODS FROM RUPTURED DAMS

I. INTRODUCTION

Dams constructed to form large water-storage reservoirs are subject to failure for several reasons. According to a survey (2) foundation failure and spillway inadequacy count for about two-thirds of all dam failures. Though not so frequent, failures due to acts of war and earthquakes may cause more serious damage since they usually occur without any previous warning.

Experience has shown that floods resulting from the sudden collapse of a dam forming a large water-storage reservoir are catastrophic. Damages are anticipated to be higher in the future, should such a mishap occurs. This will be due to both larger sizes of dams being built and the increase in industry and population density. Human settlements and the industries on which they depend usually lay in the flood plain of rivers on which dams have been constructed.

Knowledge of potential inundation areas can lead to the establishment of rational real-estate zoning criteria and procedures for the emergency evacuation of populated areas below the dam. In fact, this is the intent of California Senate Bill 896, passed into law by the California Legislature in 1972. This law requires the preparation of potential flooding maps for any dam in California, the partial or total failure of which would result in death or personal injury.

Rational and accurate methods for the preparation of such maps are, as yet, unavailable for general use. Work done at the University of California at Davis (3, 4, 5) led to the development of a rational computation procedure for predicting the flood wave resulting from the sudden and total failure of a dam in a prismatic river valley.

In this report a brief outline of the theoretical aspects of the procedure is given. For details the interested reader should consult the references cited above. The parameters involved and the variables which express the practical significance of a dam-break flood are mainly stressed. Finally, dimensionless graphs of these variables for certain values, over the practical range, of the parameters are given. With these graphs, a quick, approximate computation of the most important aspects of a flood wave following the failure of a dam is possible. An illustrative example is given.

II. THE MATHEMATICAL MODEL

1. The Governing Equations

Unsteady flow encountered in flood-wave movement in a prismatic channel is described by the Saint-Venant equations (2, 6)

$$\bar{A}\,\frac{\partial \bar{V}}{\partial \bar{x}} + \bar{B}\bar{V}\,\frac{\partial \bar{y}}{\partial \bar{x}} + \bar{B}\,\frac{\partial \bar{y}}{\partial \bar{t}} = 0 \qquad (1a)$$

$$\frac{\partial \bar{V}}{\partial \bar{t}} + \bar{V}\,\frac{\partial \bar{V}}{\partial \bar{x}} + \bar{g}\,\frac{\partial \bar{y}}{\partial \bar{x}} = \bar{g}\,(S_0 - S_f) \qquad (1b)$$

A bar over a variable indicates a dimensional quantity, unbarred variables are dimensionless. In Eqs.1: $\bar{A}(\bar{y})$ = cross-sectional area of flow; $\bar{V}(\bar{x},\bar{t}) = \bar{Q}/\bar{A}$ = average velocity of flow; $\bar{Q}(\bar{x},\bar{t})$ = discharge; $\bar{y}(\bar{x},\bar{t})$ = depth of flow; $\bar{B}(\bar{y})$ = top width of flow; $\bar{x}$ = distance from the dam, positive downstream; $\bar{t}$ = time; $\bar{g}$ = ratio of weight to mass; S_0 = channel bottom slope and S_f = friction slope. In this work S_f is evaluated using the Manning relation

$$\bar{V} = \frac{\bar{C}_U}{n}\,\bar{R}^{2/3}\,S_f^{\,1/2} \qquad (2)$$

where $\bar{C}_U = 1.0$ in the metric system and $\bar{C}_U = 1.486$ in the British system of units; n = Manning roughness coefficient; $\bar{R} = \bar{A}/\bar{P}$ = hydraulic radius and $\bar{P}$ = wetted perimeter.

2. Non-dimensionalization

Taking characteristic quantities: $\bar{L}_0$ for distance, $\bar{T}_0$ for time, $\bar{Y}_0$ for depth and $\bar{V}_0$ for velocity, the following dimensionless variables are defined

$$x = \bar{x}/\bar{L}_0\ ;\ t = \bar{t}/\bar{T}_0;\ \ y = \bar{y}/\bar{Y}_0\ ;\ \ V = \bar{V}/\bar{V}_0$$

$$A = \bar{A}/\bar{Y}_0^2\ ;\ B = \bar{B}/\bar{Y}_0\ ;\ \ R = \bar{R}/\bar{Y}_0$$

Introducing these variables into Eqs. 1 and defining

$$\bar{L}_0 = \bar{T}_0\,\bar{V}_0\ ;\qquad \bar{Y}_0 = \bar{L}_0\,S_0 \qquad (3a,b)$$

$$\bar{V}_0 = \frac{\bar{C}_U}{n}\,\bar{R}_0^{\,2/3}\,S_0^{\,1/2}\ ;\qquad \mathbf{F}_0 = \frac{\bar{V}_0}{\sqrt{\bar{g}\,\bar{Y}_0}} \qquad (3c,d)$$

the Saint-Venant equations take the dimensionless form

$$\frac{A}{B}\frac{\partial V}{\partial x} + V\frac{\partial y}{\partial x} + \frac{\partial y}{\partial t} = 0 \tag{4a}$$

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} + \frac{1}{F_0^2}\frac{\partial y}{\partial x} = \frac{1}{F_0^2}\left[1 - V^2\left(\frac{R_0}{R}\right)^{4/3}\right] \tag{4b}$$

where R_0 is the dimensionless hydraulic radius corresponding to depth $\bar{y} = \bar{Y}_0$ or to a dimensionless depth of unity.

For simplicity $\bar{Y}_0$ is taken equal to the maximum value of water depth behind the dam. Then, for a given channel geometry, bottom slope and roughness, Eqs. 3 yield the values of $\bar{V}_0$, $\bar{L}_0$, $\bar{T}_0$ and F_0.

Equations 4 are applicable to channels with non-zero bottom slope.

3. Channel Geometry

In this work a prismatic channel is assumed with breadth $\bar{B}$ related to depth $\bar{y}$ by a formula of the type

$$\bar{B} = \bar{C}\,\bar{y}^M \tag{5}$$

where $\bar{C}$ and M are constants. Non-dimensionalization of Eq. 5 yields

$$B = C\,y^M \tag{6}$$

where

$$C = \bar{C}\,\bar{Y}_0^{M-1} \tag{7}$$

If $\bar{B}_0$ denotes the breadth corresponding to depth $\bar{y} = \bar{Y}_0$, it is easily seen that $C = \bar{B}_0/\bar{Y}_0$, the relative top width of the channel cross-section at the dam site.

4. Solution of the Equations

For details in solving Eqs. 4 and for the initial conditions, upstream and downstream boundary conditions used in the solution, reference should be made to (3, 4, 5).

In brief Eqs. 4 are transformed into characteristic form and solved numerically over the irregular grid formed by the characteristic lines in the x-t plane using a predictor-corrector scheme.

The water behind the dam is assumed to be at rest prior to dam failure and the downstream channel is dry. A generalized Ritter solution (3, 4) is taken to represent initial conditions along a forward characteristic shrunk to the point x = 0, t = 0 in the x-t plane.

The front of the negative wave propagating into the still water in the reservoir defines the upstream boundary of the flow field where conditions are the same as the undisturbed initial conditions. Upstream boundary conditions are determined in this fashion until about the negative wave front reaches the upstream reservoir end at time t_E given by

$$t_E = 2\mathbf{F}_0 \sqrt{M+T} \tag{8}$$

Shortly before that time, when a depth smaller than a prescribed depth y_m is obtained at the moving upstream boundary, a fictitious stream of the same depth is introduced at the ultimate location of the upstream boundary and assumed existing thereafter. The velocity is determined using the backward characteristic relation. Typical values of y_m are: $y_m = 0.01$ for $\mathbf{F}_0 \geq 0.5$ and $y_m = 0.03$ for $\mathbf{F}_0 = 0.025$.

In the region very close to the wave tip where $y \to 0$ and $dy/dx \to -\infty$ the formal numerical solution is very costly to apply. Instead, the water surface profile is determined analytically using a simplified form of Eq. 4b suggested by Whitham (7) and based on physical considerations of the tip region. Typical values of y up to which the formal computation proceeds are in the order of 0.04.

Solution of Eqs. 4 yield values of depth and velocity at the nodes of the characteristics grid in the x-t plane. Data pertaining to stage and discharge hydrographs at various locations along the channel are obtained through linear interpolation between node values.

III. DIMENSIONLESS FLOOD GRAPHS

1. Dam-break Flood Variables

For practical purposes it is desirable and adequate that the time of arrival of the wave front as well as the maximum flood level and the time of its occurrence after dam rupture, be known for any given location downstream of the dam. In some cases and for preliminary investigations a rough estimate of the above factors is sufficient. Under these conditions approximate results can be drawn quickly from properly prepared graphs representing solutions to a series of simple cases.

A simplification of the river valley geometry leads to a prismatic channel of general parabolic cross-section as defined by Eq. 5. In this case Eqs. 4 contain three parameters, namely $\mathbf{F}_0$, M and C, besides the dependent variables y and V and the independent variables x and t. Thus the variables y and V are functions of five variables, that is

$$y = q\ (x,\ t,\ \mathbf{F}_0,\ M,\ C) \tag{9}$$
$$V = r\ (x,\ t,\ \mathbf{F}_0,\ M,\ C) \tag{10}$$

For given values of x, $\mathbf{F}_0$, M and C, Eqs. 9 and 10 represent the stage and velocity hydrographs, respectively.

From the stage hydrograph and for practical purposes, one is mainly interested in the maximum value of depth, y_M, occurring at time t_M such that in Eq. 9

$$\left.\frac{\partial y}{\partial t}\right|_{t=t_M} = 0 \tag{11}$$

Then

$$y_M = q\ (x,\ t_M,\ \mathbf{F}_0,\ M,\ C) \tag{12}$$

Solving Eq. 11 for t_M, one obtains

$$t_M = s\ (x,\ \mathbf{F}_0,\ M,\ C) \tag{13}$$

Introduction of Eq. 13 into Eq. 12 yields

$$y_M = u\ (x,\ \mathbf{F}_0,\ M,\ C) \tag{14}$$

The speed of propagation of the wave front, W, is equal to the flow velocity at the wave front. If x_W and t_W designate the wave-front location in the x-t plane, then

$$W = \frac{dx_W}{dt_W} = r\ (x_W,\ t_W,\ \mathbf{F}_0,\ M,\ C) \tag{15}$$

Integration of Eq. 15 and solution for t_W yields

$$t_W = v\ (x_W,\ \mathbf{F}_o,\ M,\ C) \tag{16}$$

The left-hand side of each of Eqs. 13, 14 and 16, constituting the practically important dam-break flood variables, can be plotted versus x with C as a parameter in one sheet of paper for given values of $\mathbf{F}_o$ and M. In the triangular cross-section, defined for M = 1, C is no longer a parameter because the hydraulic radius through which C enters Eqs. 4 is a linear function of y and thus C is eliminated. In this case $\mathbf{F}_o$ may be used as a parameter to distinguish curves in the same plot.

2. Range of Parameters

For the preparation of dimensionless graphs of the dam-break flood variables actual conditions are assumed to vary between the following extremes:

Condition	Minimum value	Maximum value
Water depth behind dam, $\bar{Y}_o$	10 m (32.8 ft)	200 m (656 ft)
Channel bottom slope, S_o	0.0005	0.010
Manning roughness coefficient, n	0.015	0.150
Cross-section exponent, M	0	1
Relative top width, $C = \bar{B}_o/\bar{Y}_o$	1	50
Froude number $\mathbf{F}_o = \bar{V}_o/\sqrt{\bar{g}\ \bar{Y}_o}$	0.025	5

The extreme values of $\mathbf{F}_o$ are determined from the combinations of $\bar{Y}_o$, S_o, n, M and C leading to extreme values of $\bar{V}_o$.

3. Data Acquisition

For preparing the dimensionless flood graphs, data were obtained for the following values of the parameters $\mathbf{F}_o$, M and C in the above listed range:

$\mathbf{F}_o$ =	0.025	0.10	0.50	1	2	5
M =	0	0.50	1			
C =	1	2	5	10	50	

The wave-front location at any time is given directly by the solution. The value of y_M in each stage hydrograph is determined as the maximum of discrete values of y obtained in the course of the solution. The latter are close enough to insure practically insignificant deviation from the true maximum. The time at which y_M occurs is the value of t_M.

The solution progressed in time until values of y_M and t_M were obtained for a cross-section at a distance at least $m\bar{Y}_o$ below the dam. Minimum value of m is 1000. If $\bar{x}_M$ designates the abscissa of a flood peak, then

$$\max \{ \bar{x}_M \} \geq m \, \bar{Y}_0 \qquad (17)$$

or

$$\max \{ x_M \} \geq m \, S_0 \qquad (18)$$

For given values of $\mathbf{F}_0$, M and C, Eq. 18 must be satisfied for all possible values of S_0 in the respective range. Hence Eq. 18 is rewritten as

$$\max \{ x_M \} \geq m \cdot \max \{ S_0 \} \qquad (S_0 \leq 0.010) \qquad (19)$$

In this case one obtains from Eqs. 3c, d

$$S_0 = \bar{g} \left(\frac{n\mathbf{F}_0}{\bar{C}_U}\right)^2 \frac{\bar{Y}_0}{\bar{R}_0^{4/3}} \qquad (20)$$

For any fixed value of $\bar{Y}_0$ maximum value of S_0 results when n attains its maximum permissible value of 0.150. For such value of n, $\bar{Y}_0$ is varied over its range and the maximum value of S_0 is found. If the latter is less than 0.010, it is inserted into Eq. 19. Otherwise max { S_0 } = 0.010.

4. Arrangement of the Graphs

The dimensionless flood graphs are arranged in three sets, one for each of the dam-break flood variables, namely t_W, y_M and t_M. For easier identification and use each set is included in a separate Appendix. In Appendix A the dimensionless graphs for the time of arrival of the wave front, t_W, are given, Figs. A1 to A15. Appendix B contains the dimensionless graphs for the maximum flood level, y_M, Figs. B1 to B15. Finally in Appendix C the diemsnionless graphs for the time of occurrence of the maximum flood level, t_M, are found, Figs. C1 to C15.

In each Appendix there are three subsets, one for each value of the cross-section exponent M, that is M = 0, 0.50 and 1. In each subset individual sheets are arranged in ascending values of $\mathbf{F}_0$.

5. Example of Using the Graphs

An approximately prismatic river valley is 400 ft and 600 ft wide at distances, respectively, 20 ft and 86 ft from the valley floor. The roughness of the valley is estimated at n = 0.070 and the slope is approximately S_0 = 0.001. Water is impounded behind a dam at 86 ft depth. It is required to determine the flood characteristics in case the dam instaneously and completely collapses.

Solution. Fitting a curve of the form of Eq. 5 through the boundary of the valley one finds $M = 0.278$ and $\bar{C} = 175\ ft^{0.722}$ (dimensions of $\bar{C}$ are ft to the $(1-M)$ power). Taking $Y_0 = 86$ ft, one finds by Eq. 7 $C = 7$ and by Eqs. 3 : $L_0 = 86{,}000$ ft or 16.3 mi., $V_0 = 10.54$ ft/sec, $T_0 = 2.265$ hr and $F_0 = 0.20$.

Using the graphs in Figs. A2, A3 values of t_W at the desired locations are obtained for $F_0 = 0.10$ and $F_0 = 0.50$, respectively, and $M = 0$, $C = 7$. In a similar way, from Figs. A8, A9 values of t_W are found for $F_0 = 0.10$ and $F_0 = 0.50$, respectively, and $M = 0.50$, $C = 7$. Linear interpolation yields the values of t_W for $F_0 = 0.20$ and each value of M. Finally, a second interpolation between the latter yields values of t_W for $F_0 = 0.20$ and $M = 0.278$. An arrangement of data in table form, as shown in Table 1, makes the task easier.

A completely analogous procedure using the appropriate graphs in Appendices B and C yields the values of y_M and t_M as shown in Tables 2 and 3.

TABLE 1

Time of arrival of the wave front

Distance		M = 0			M = 0.50			M = 0.278	
$\bar{x}$	x	F_o			F_o			F_o = 0.20	
miles		0.10	0.50	0.20	0.10	0.50	0.20	t_w	$\bar{t}_w$, hr
6.00	0.368	0.25	0.375	0.281	0.22	0.28	0.235	0.255	0.58
8.15	0.5	0.40	0.50	0.425	0.36	0.40	0.370	0.395	0.90
16.30	1.0	1.02	1.20	1.065	0.95	1.00	0.962	1.008	2.28
24.45	1.5	1.80	1.90	1.825	1.65	1.75	1.675	1.742	3.94
32.60	2.0	2.65	2.85	2.700	2.43	2.60	2.472	2.573	5.83
48.90	3.0	4.65	4.875	4.706	4.12	4.30	4.165	4.405	9.98

TABLE 2

Maximum flood level

Distance		M = 0			M = 0.50			M = 0.278	
$\bar{x}$ miles	x	F_0			F_0			$F_0 = 0.20$	
		0.10	0.50	0.20	0.10	0.50	0.20	y_M	$\bar{y}_M$, ft
6.00	0.368	0.433	0.395	0.424	0.524	0.488	0.515	0.475	40.8
8.15	0.5	0.408	0.378	0.400	0.500	0.470	0.492	0.451	38.8
16.30	1.0	0.344	0.325	0.339	0.440	0.423	0.436	0.393	33.8
24.45	1.5	0.305	0.295	0.302	0.405	0.392	0.402	0.358	30.8
32.60	2.0	0.279	0.269	0.276	0.378	0.369	0.376	0.332	28.6
48.90	3.0	0.235	0.230	0.234	0.340	0.333	0.338	0.292	25.1

TABLE 3

Time of occurrence of maximum flood level

Distance		M = 0			M = 0.50			M = 0.278	
$\bar{x}$ miles	x	F_o			F_o			F_o = 0.20	
		0.10	0.50	0.20	0.10	0.50	0.20	t_M	$\bar{t}_M$, hr
6.00	0.368	0.58	0.75	0.622	0.54	0.70	0.580	0.599	1.36
8.15	0.5	0.78	0.90	0.810	0.75	0.90	0.788	0.798	1.81
16.30	1.0	1.60	1.80	1.650	1.53	1.70	1.572	1.607	3.64
24.45	1.5	2.45	2.65	2.500	2.35	2.50	2.388	2.438	5.52
32.60	2.0	3.40	3.60	3.450	3.22	3.40	3.265	3.347	7.58
48.90	3.0	5.45	5.65	5.500	5.05	5.20	5.088	5.271	11.93

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APPENDIX A

GRAPHS FOR THE TIME OF ARRIVAL OF THE WAVE FRONT

(Figs. A1 to A15)

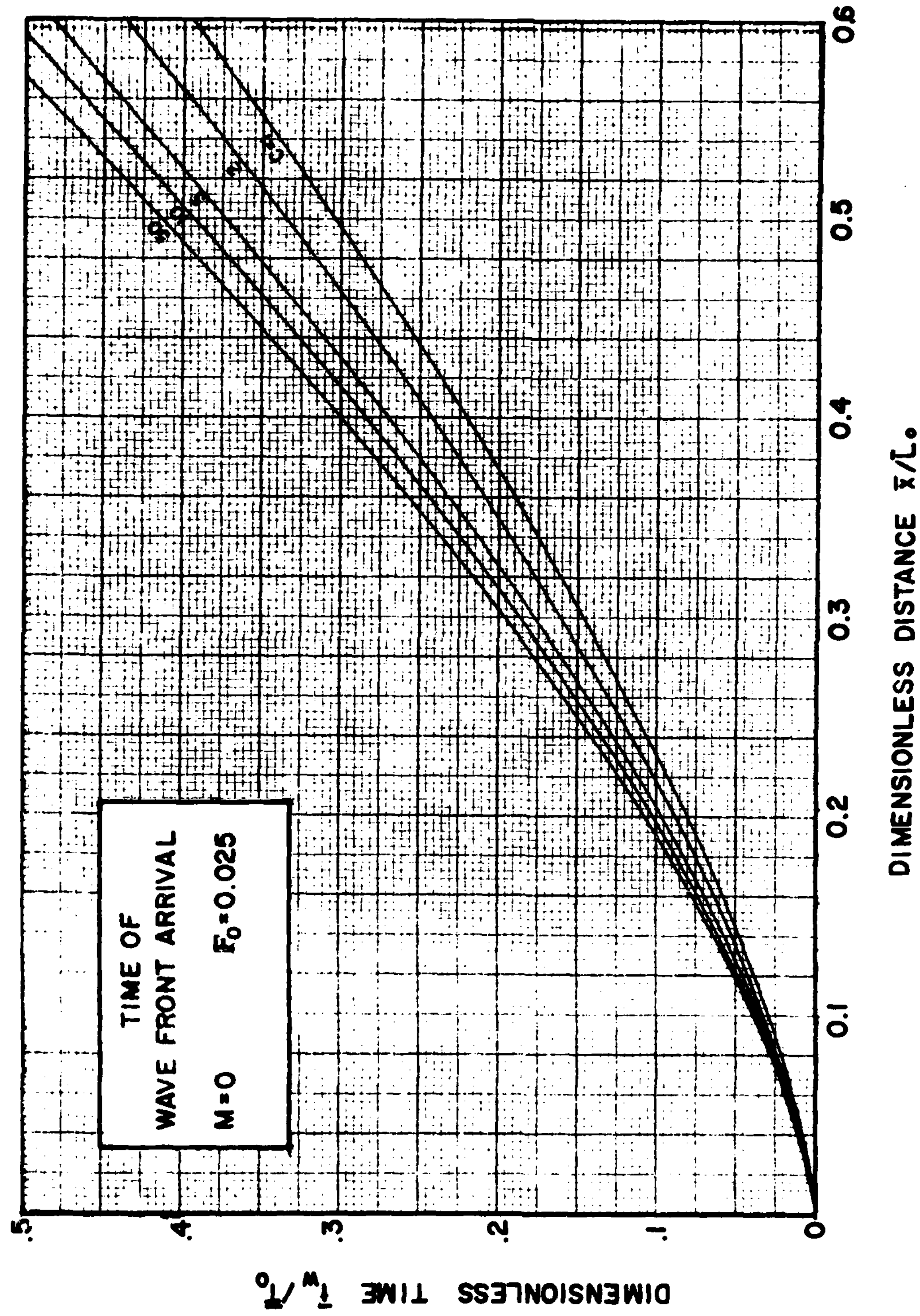
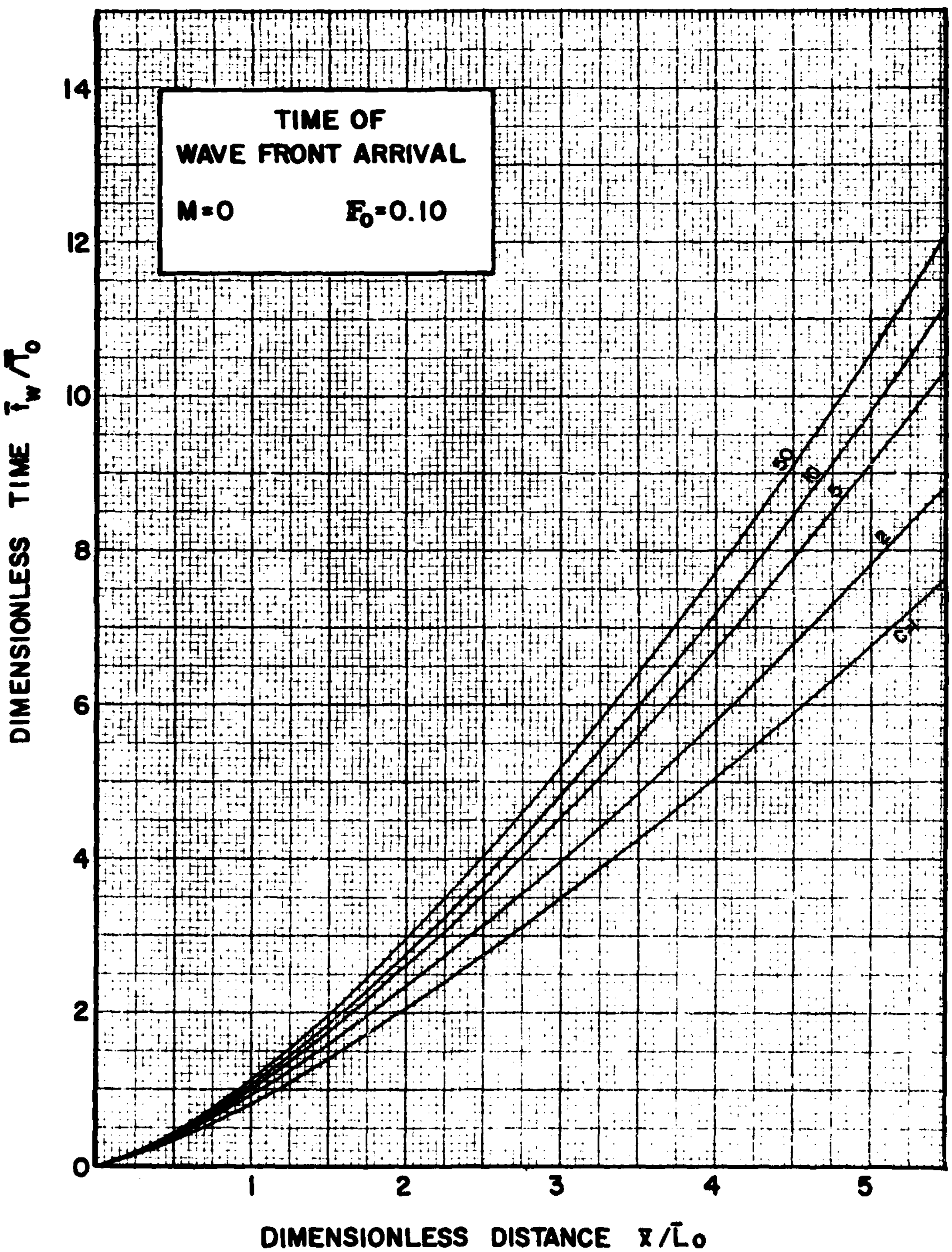
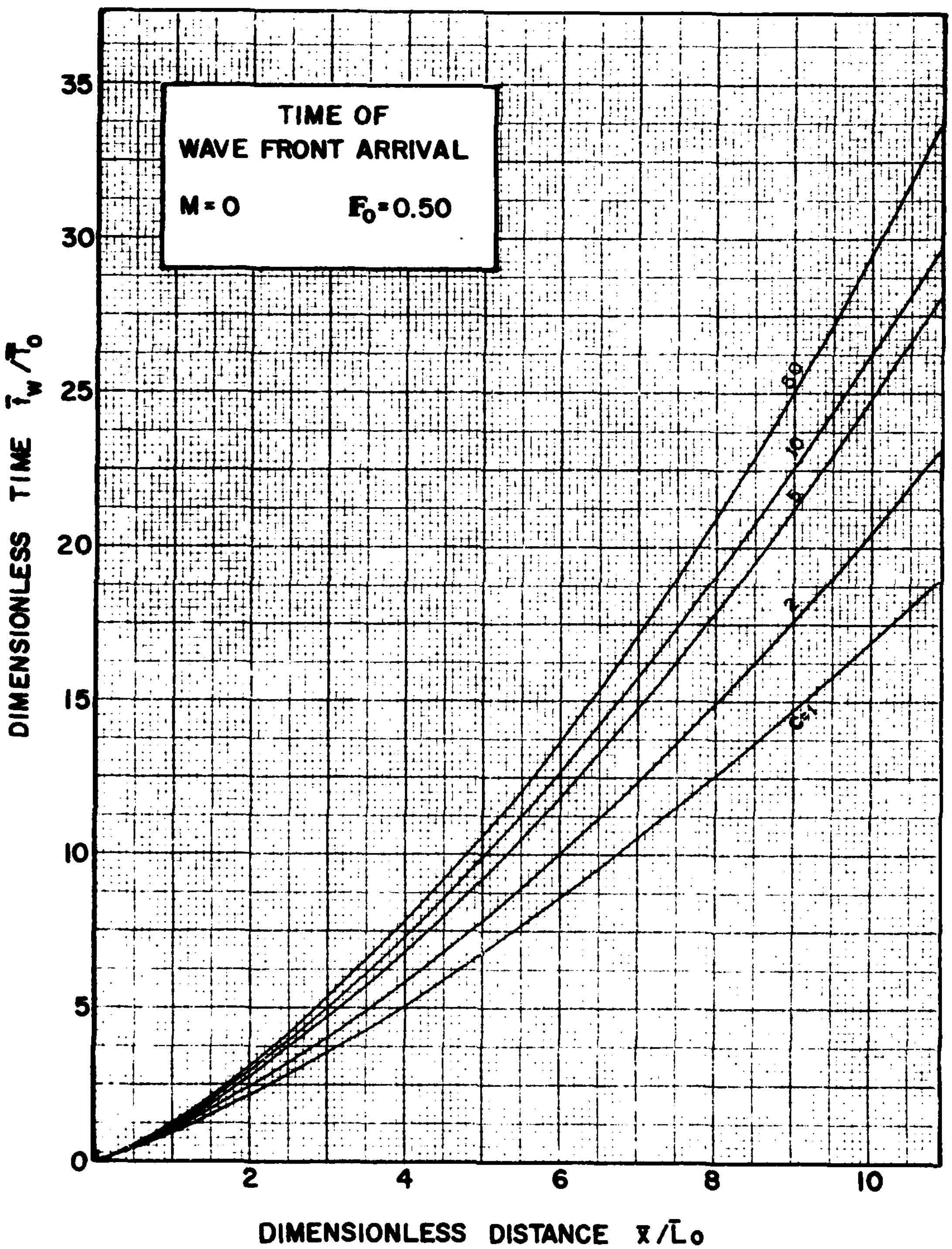

TIME OF
WAVE FRONT ARRIVAL
M=O
$\bar{F}_0$=0.025
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_o$
0
0.1
0.2
0.3
0.4
0.5
0.6
.1
.2
.3
.4
.5

Fig. A1



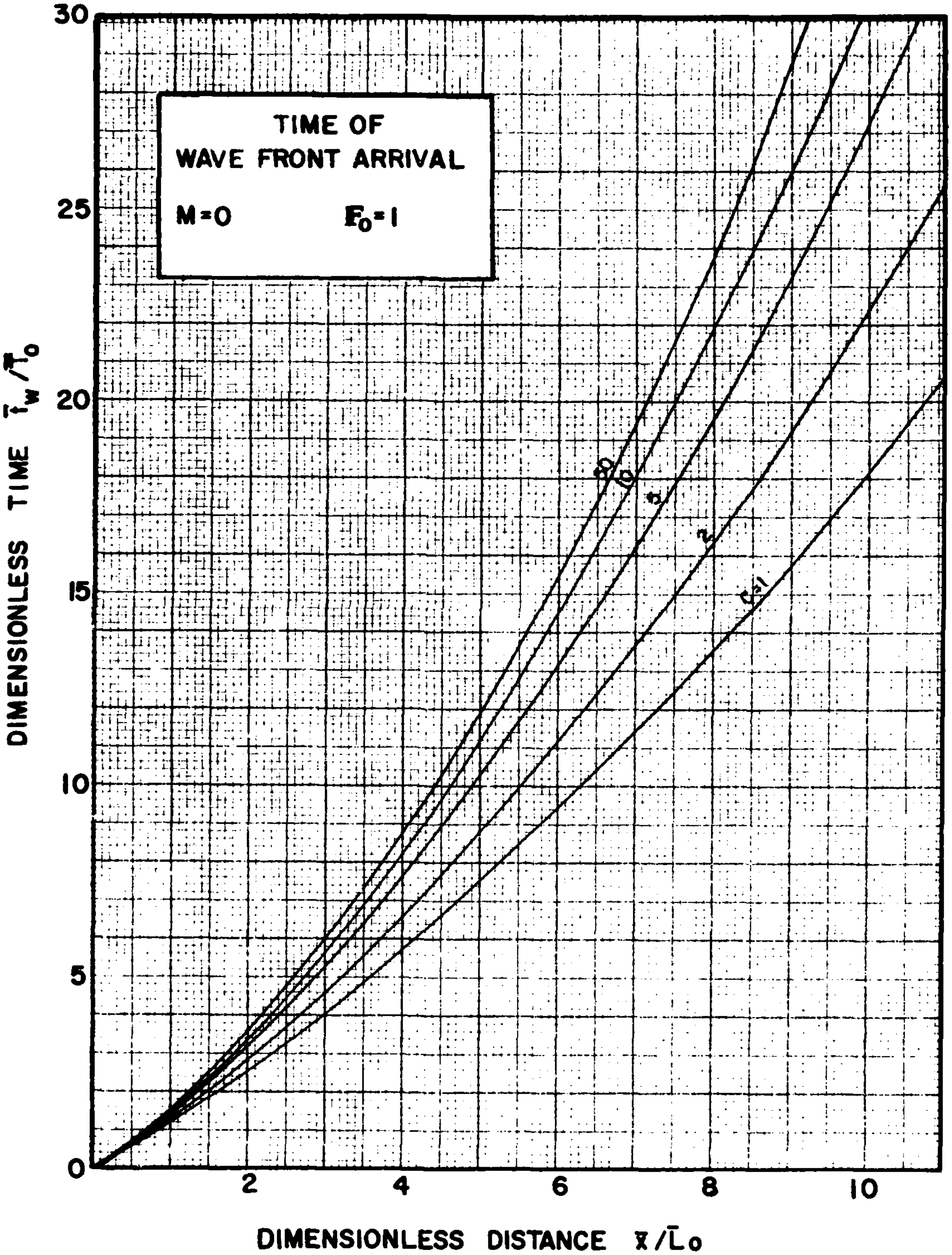
TIME OF
WAVE FRONT ARRIVAL
M=0
$\bar{F}_0$=0.10
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
0
2
4
6
8
10
12
14
1
2
3
4
5
50
10
5
2

Fig. A2

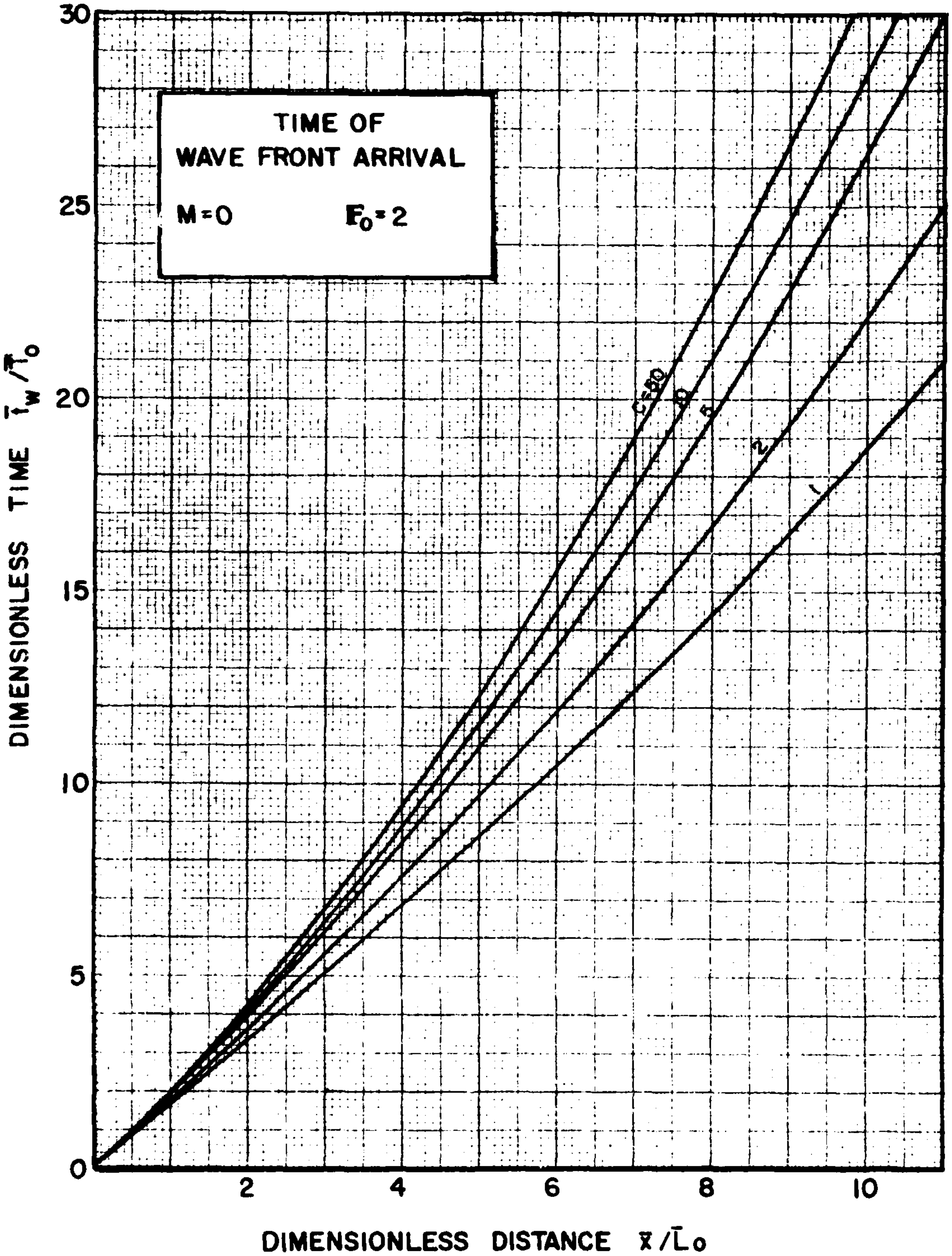


TIME OF
WAVE FRONT ARRIVAL
M = 0
F_0 = 0.50
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_o$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
0
5
10
15
20
25
30
35
2
4
6
8
10
50
10
5
2
C=1

Fig. A3



TIME OF
WAVE FRONT ARRIVAL
M=0
F0=1
30
25
20
15
10
5
0
2
4
6
8
10
DIMENSIONLESS TIME tw/To
DIMENSIONLESS DISTANCE x/Lo



TIME OF
WAVE FRONT ARRIVAL
M=0
F_0=2
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_o$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
0
5
10
15
20
25
30
2
4
6
8
10
C=20
10
5
2
1

Fig. A5

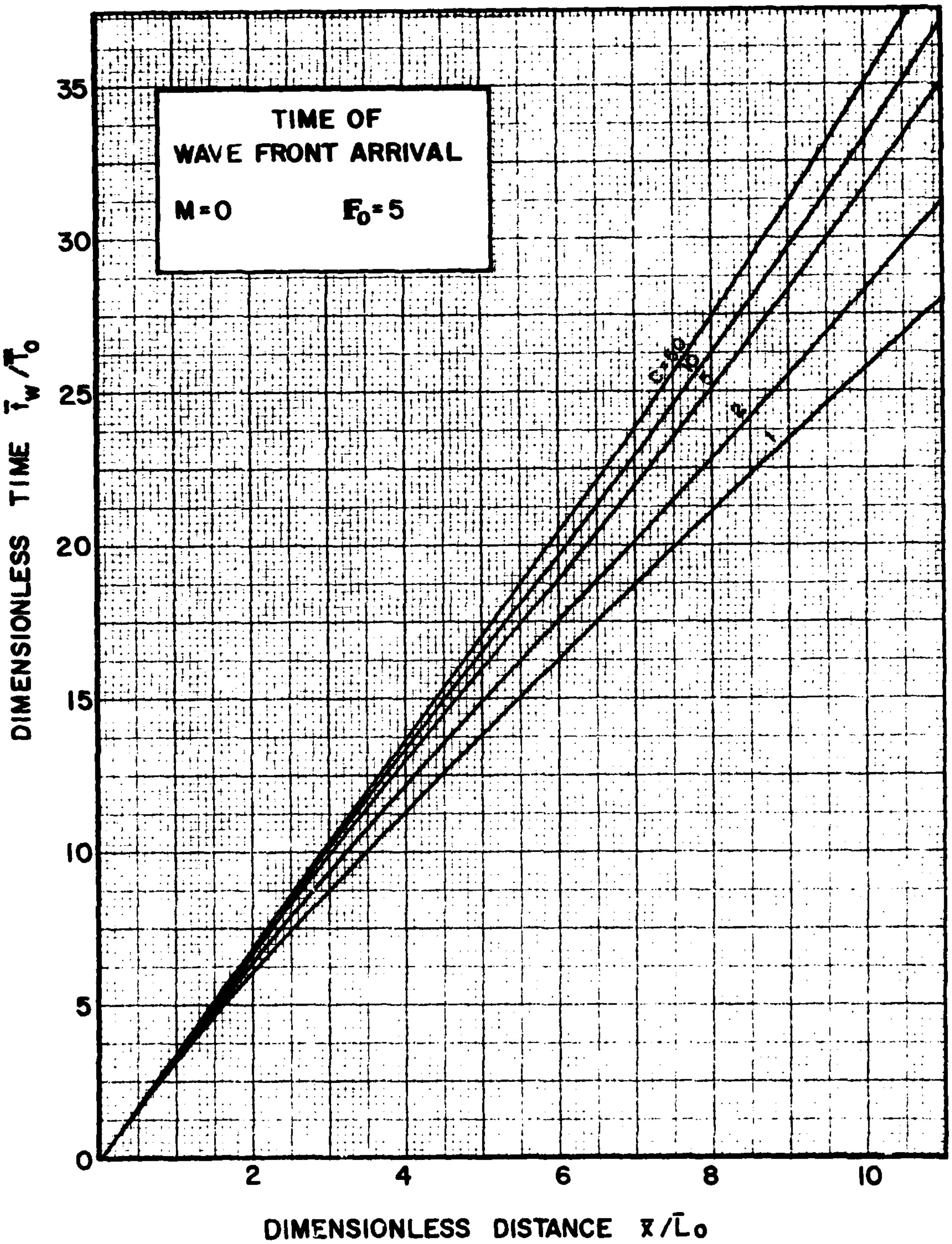

TIME OF
WAVE FRONT ARRIVAL
M=0
E_0=5
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_o$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
0
5
10
15
20
25
30
35
2
4
6
8
10
1
2

Fig. A6

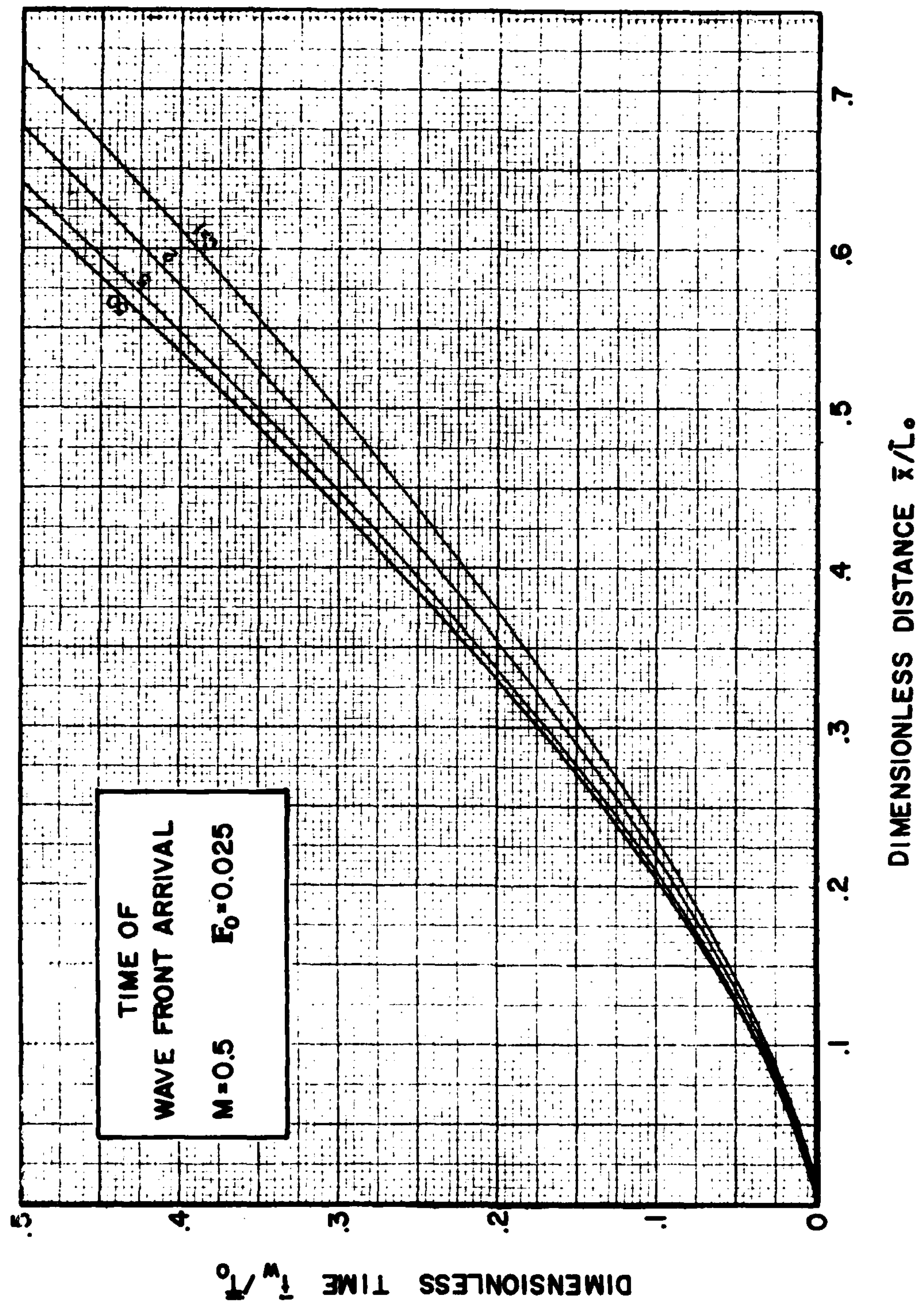

TIME OF
WAVE FRONT ARRIVAL
M=0.5
E_0=0.025
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_o$
0
.1
.2
.3
.4
.5
.6
.7

Fig. A7

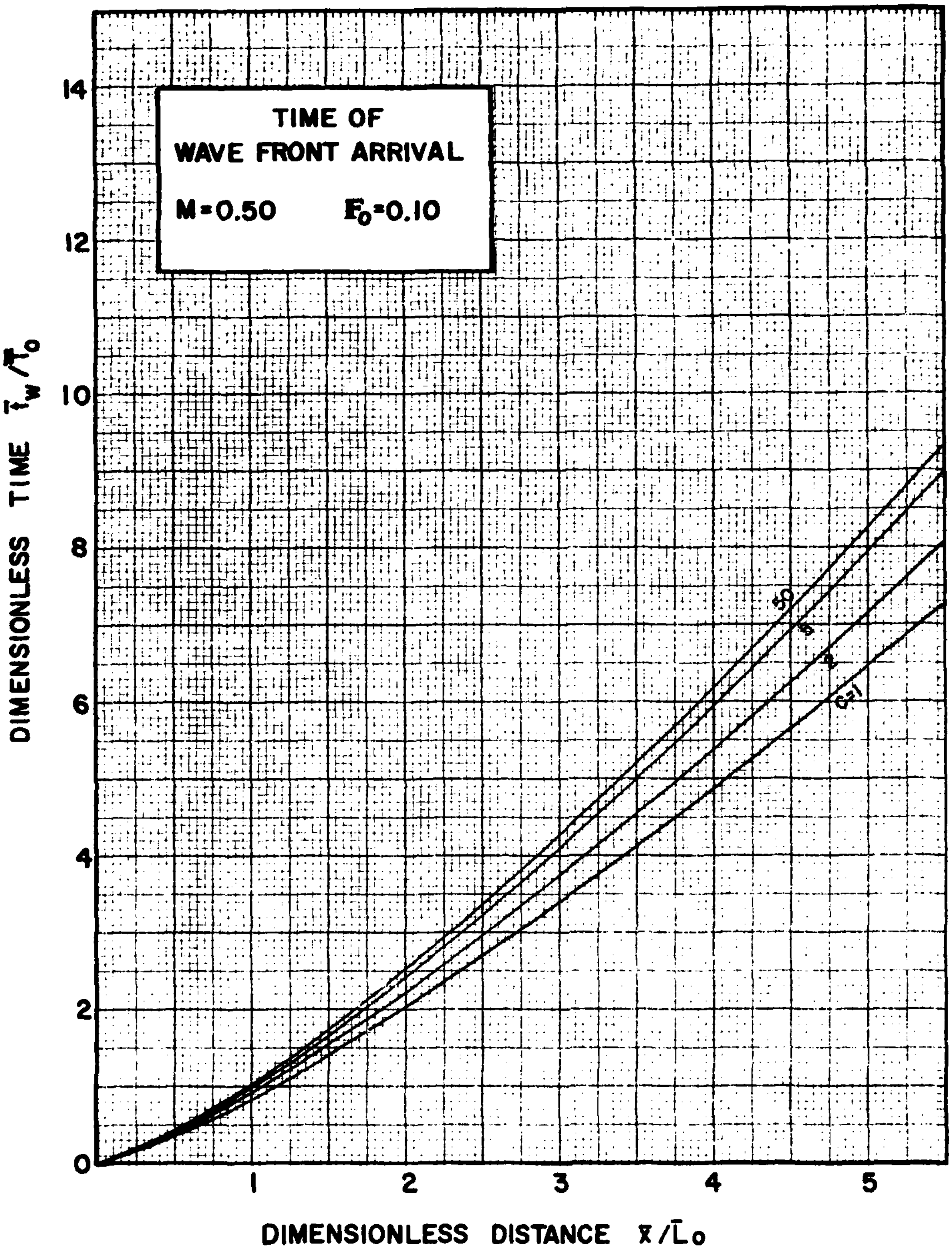

TIME OF
WAVE FRONT ARRIVAL
M=0.50 F0=0.10
DIMENSIONLESS TIME
DIMENSIONLESS DISTANCE
0
2
4
6
8
10
12
14
1
2
3
4
5
50
C=1

Fig. A8

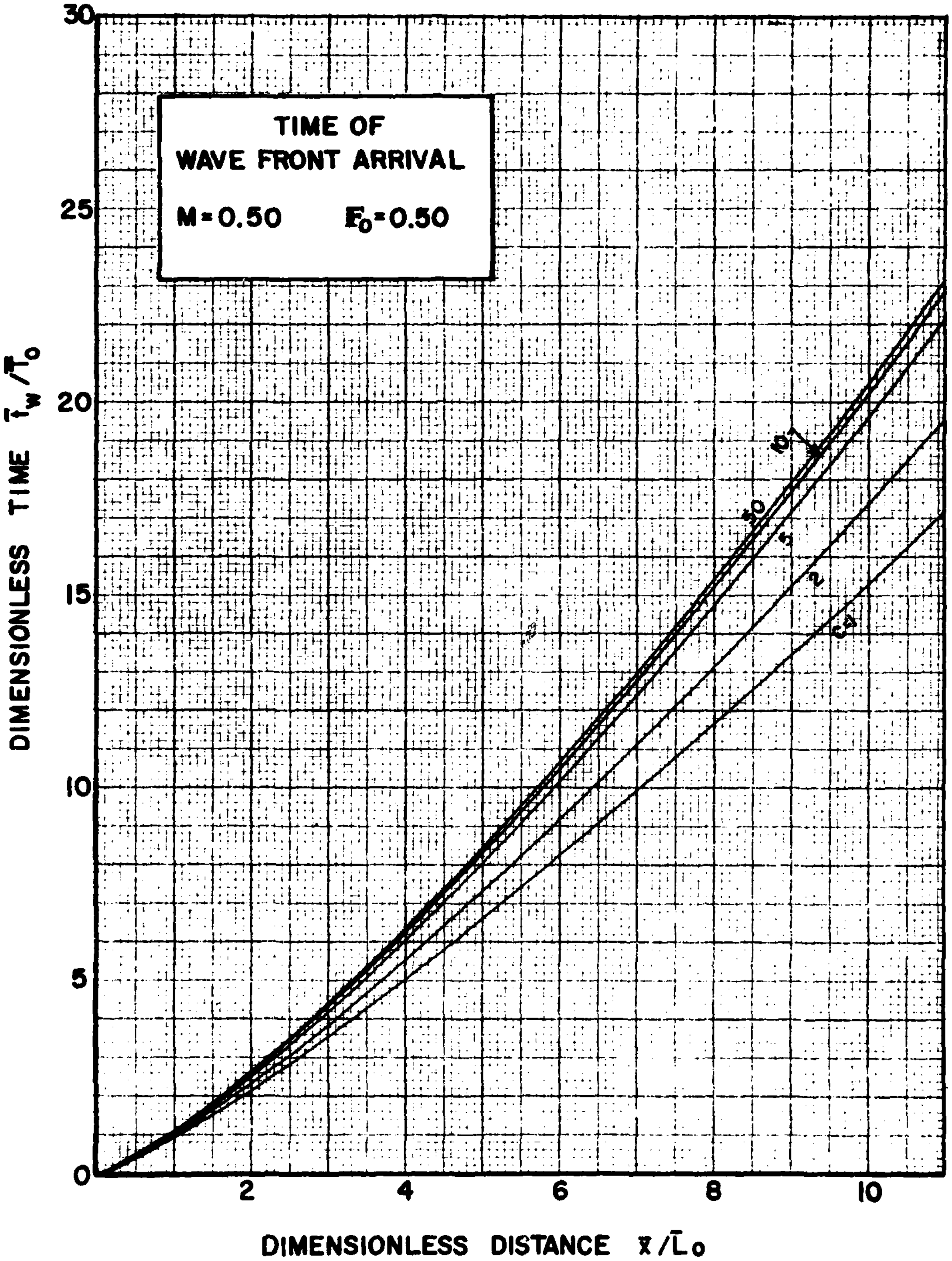

TIME OF
WAVE FRONT ARRIVAL
M = 0.50
E_0 = 0.50
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
0
5
10
15
20
25
30
2
4
6
8
10
100
50
5
2

Fig. A9

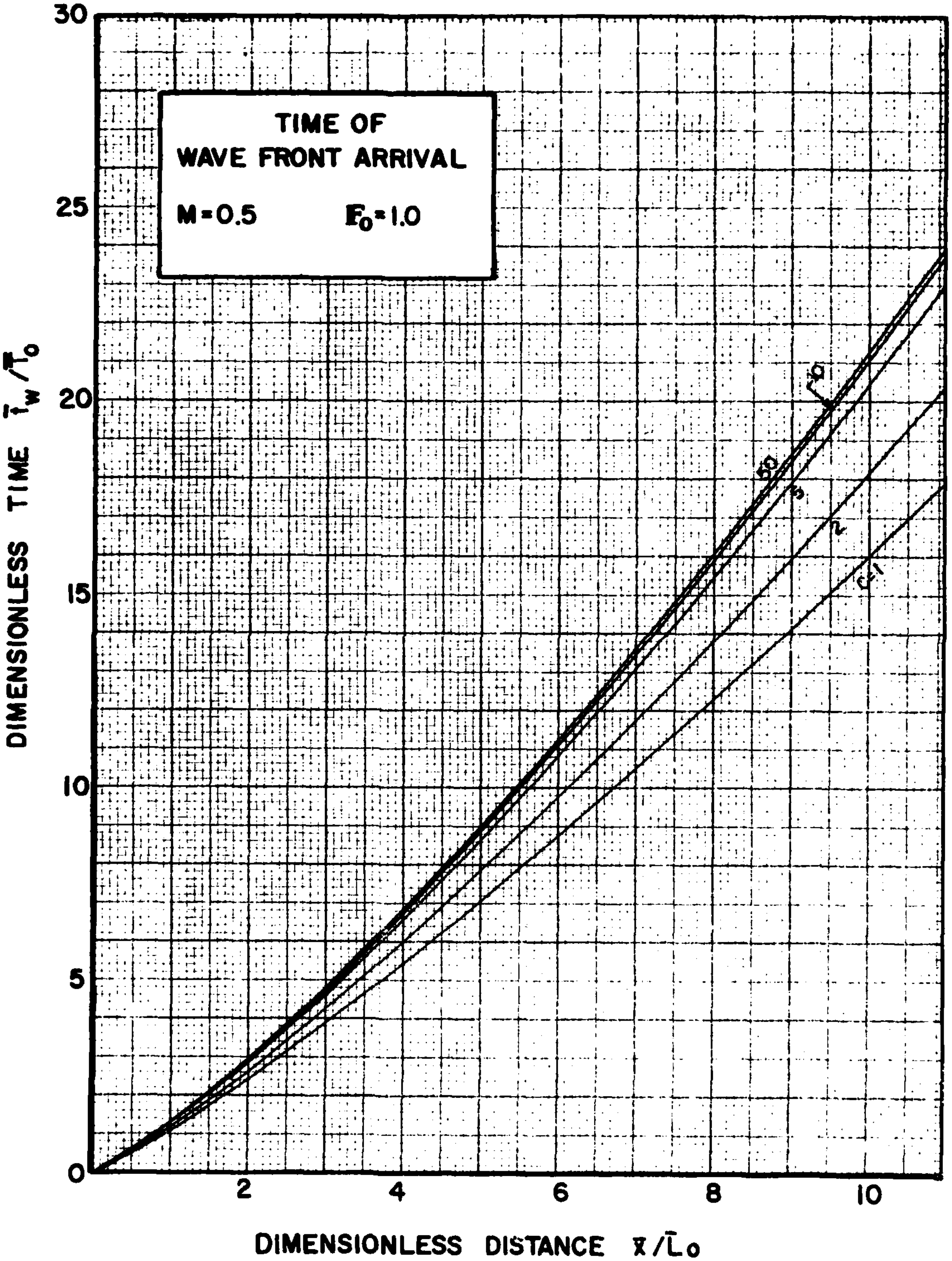

TIME OF
WAVE FRONT ARRIVAL
M = 0.5
F0 = 1.0
DIMENSIONLESS TIME
DIMENSIONLESS DISTANCE
30
25
20
15
10
5
0
2
4
6
8
10

Fig. A10

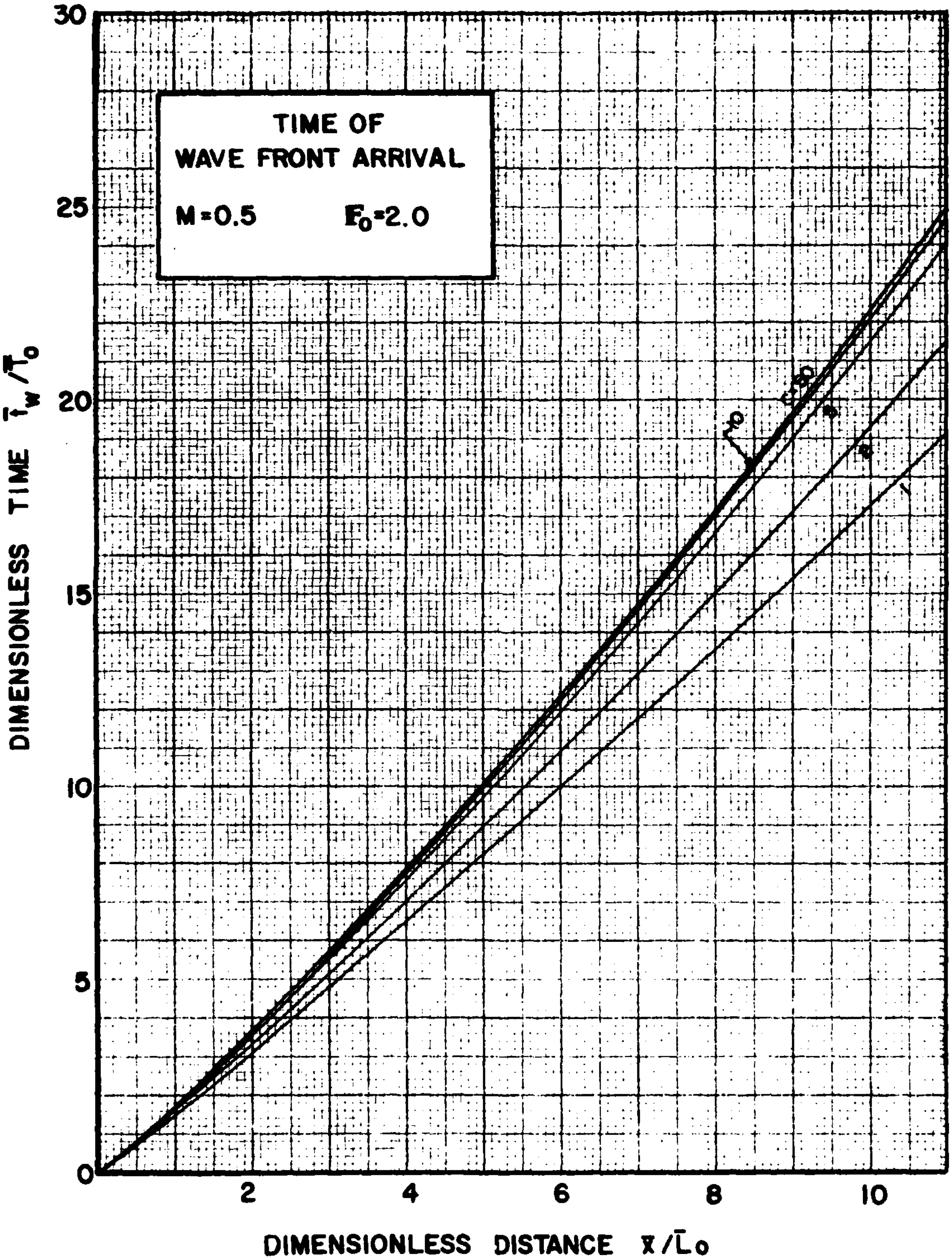
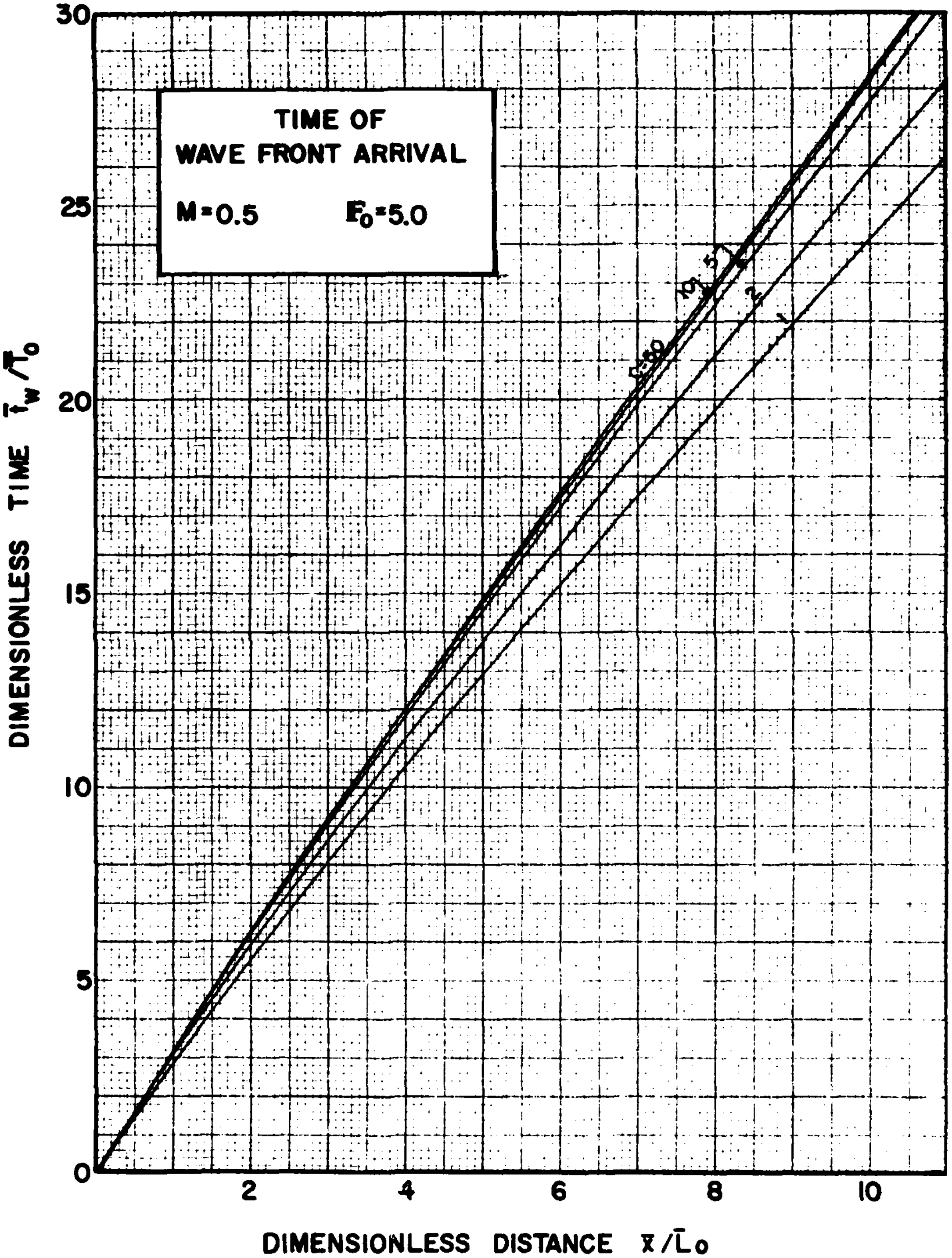

TIME OF
WAVE FRONT ARRIVAL
M = 0.5 F0 = 2.0
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
0
5
10
15
20
25
30
2
4
6
8
10

Fig. A11



TIME OF
WAVE FRONT ARRIVAL
M=0.5 $\bar{E}_0$=5.0
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
0
5
10
15
20
25
30
2
4
6
8
10
1
2
5
10
C=50

Fig. A12

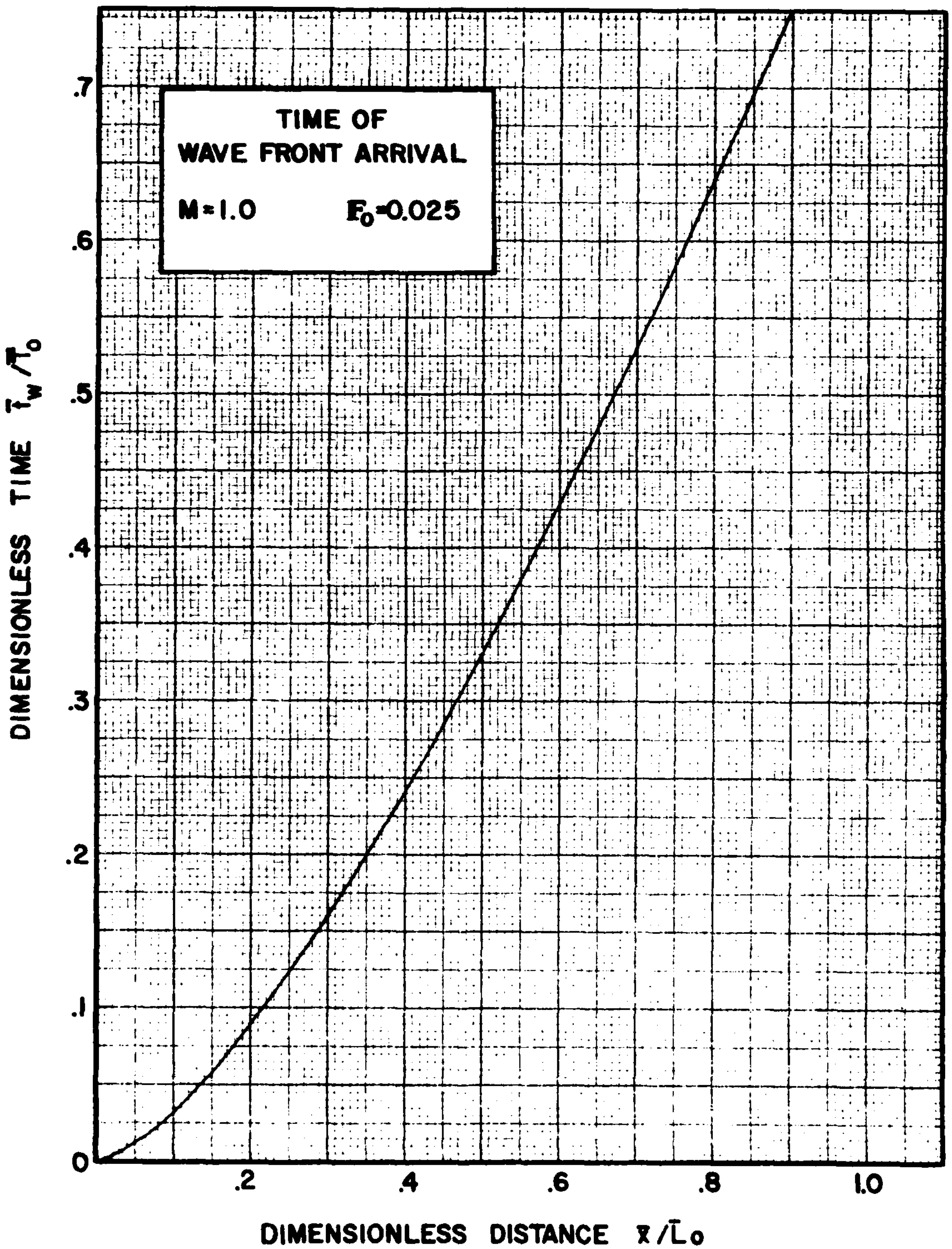
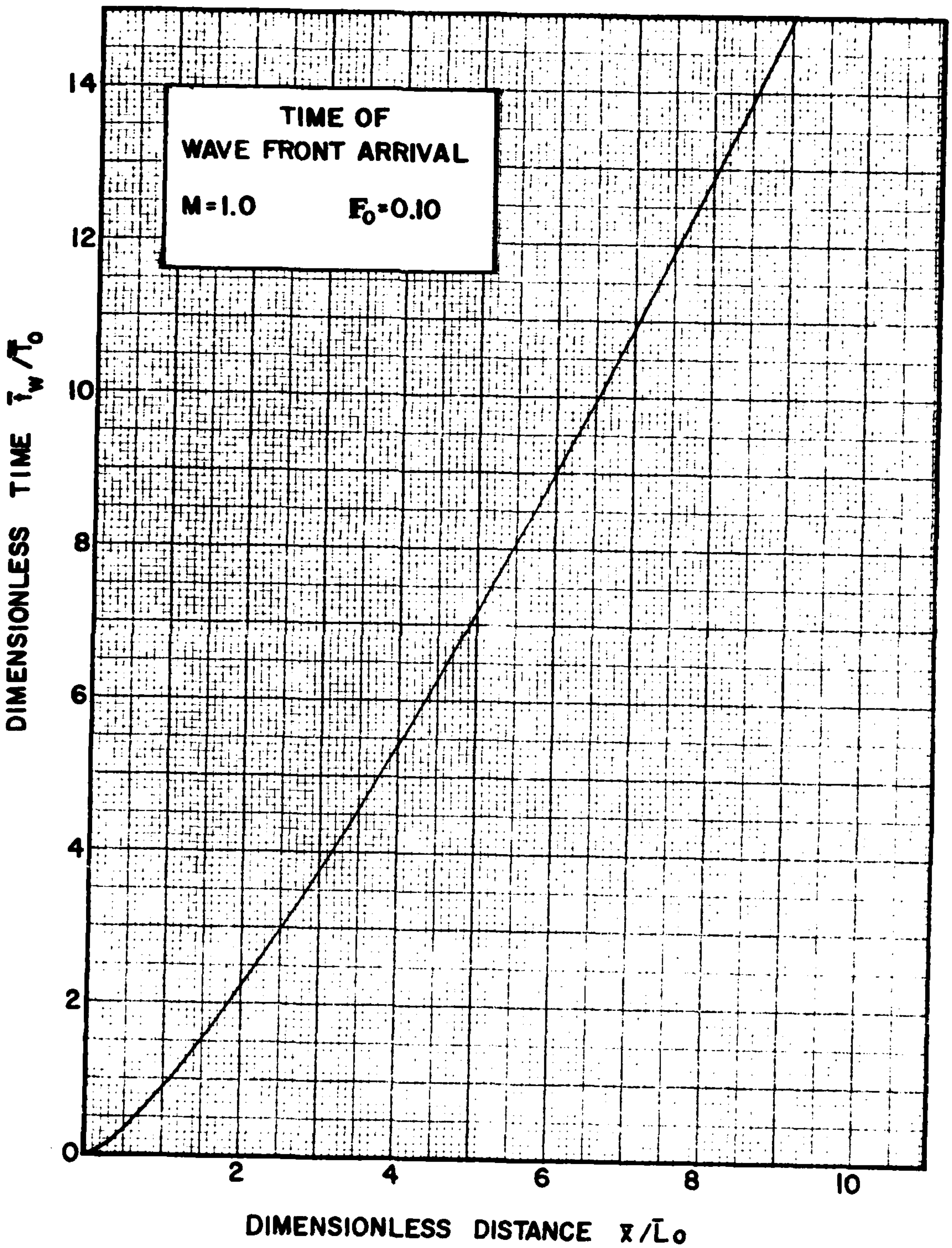

TIME OF
WAVE FRONT ARRIVAL
M=1.0
$\bar{F}_0$=0.025
DIMENSIONLESS TIME $\bar{\tau}_w/\bar{T}_o$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
0
.1
.2
.3
.4
.5
.6
.7
.2
.4
.6
.8
1.0

Fig. A13



TIME OF
WAVE FRONT ARRIVAL
M=1.0 $\bar{F}_0$=0.10
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_o$
DIMENSIONLESS DISTANCE $\bar{X}/\bar{L}_o$
0
2
4
6
8
10
12
14

Fig. A14

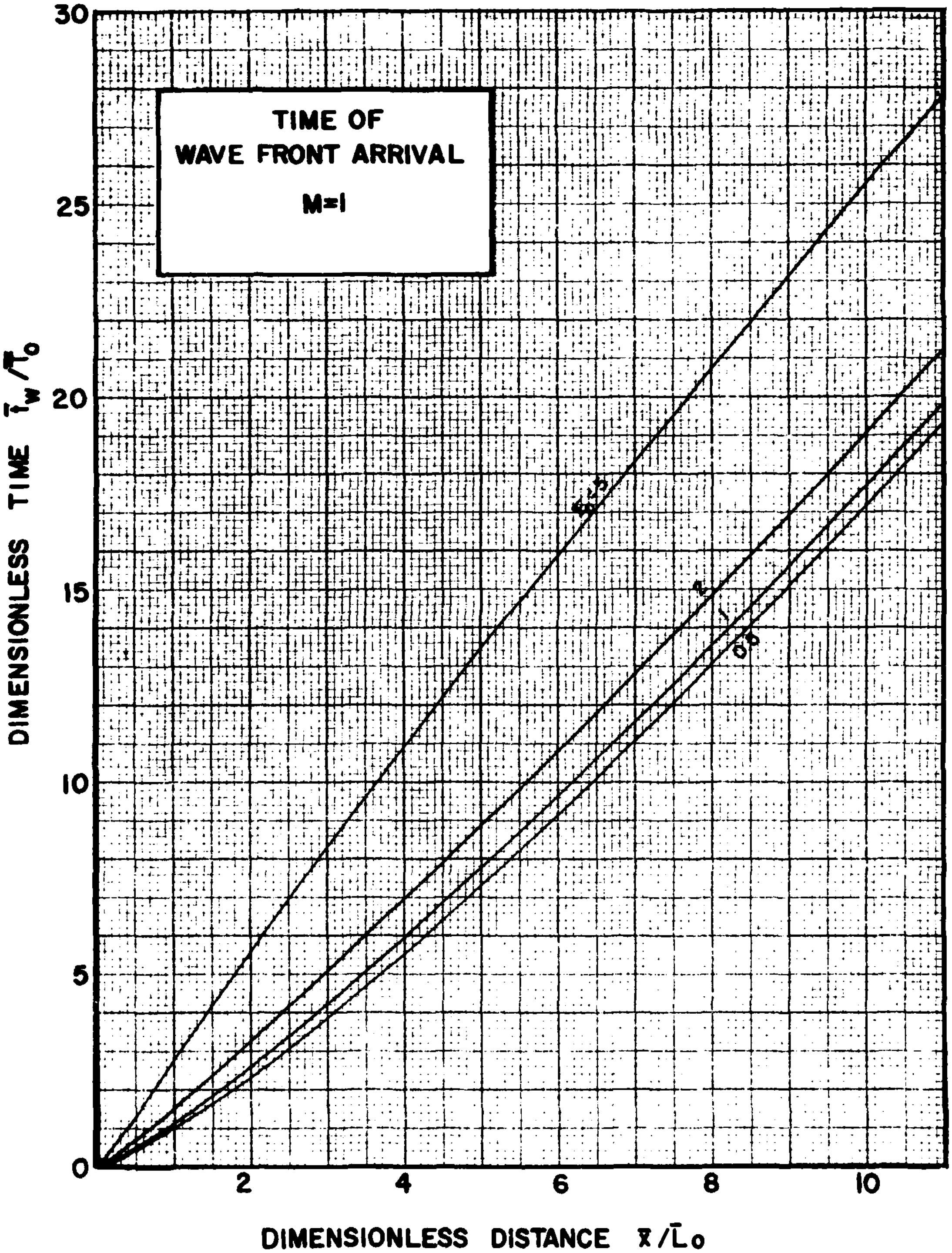

TIME OF
WAVE FRONT ARRIVAL
M=1
DIMENSIONLESS TIME $\bar{t}_w/\bar{T}_o$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
0
5
10
15
20
25
30
2
4
6
8
10
2
1

Fig. A15

APPENDIX B

GRAPHS FOR THE MAXIMUM FLOOD LEVEL

(Figs. B1 to B15)

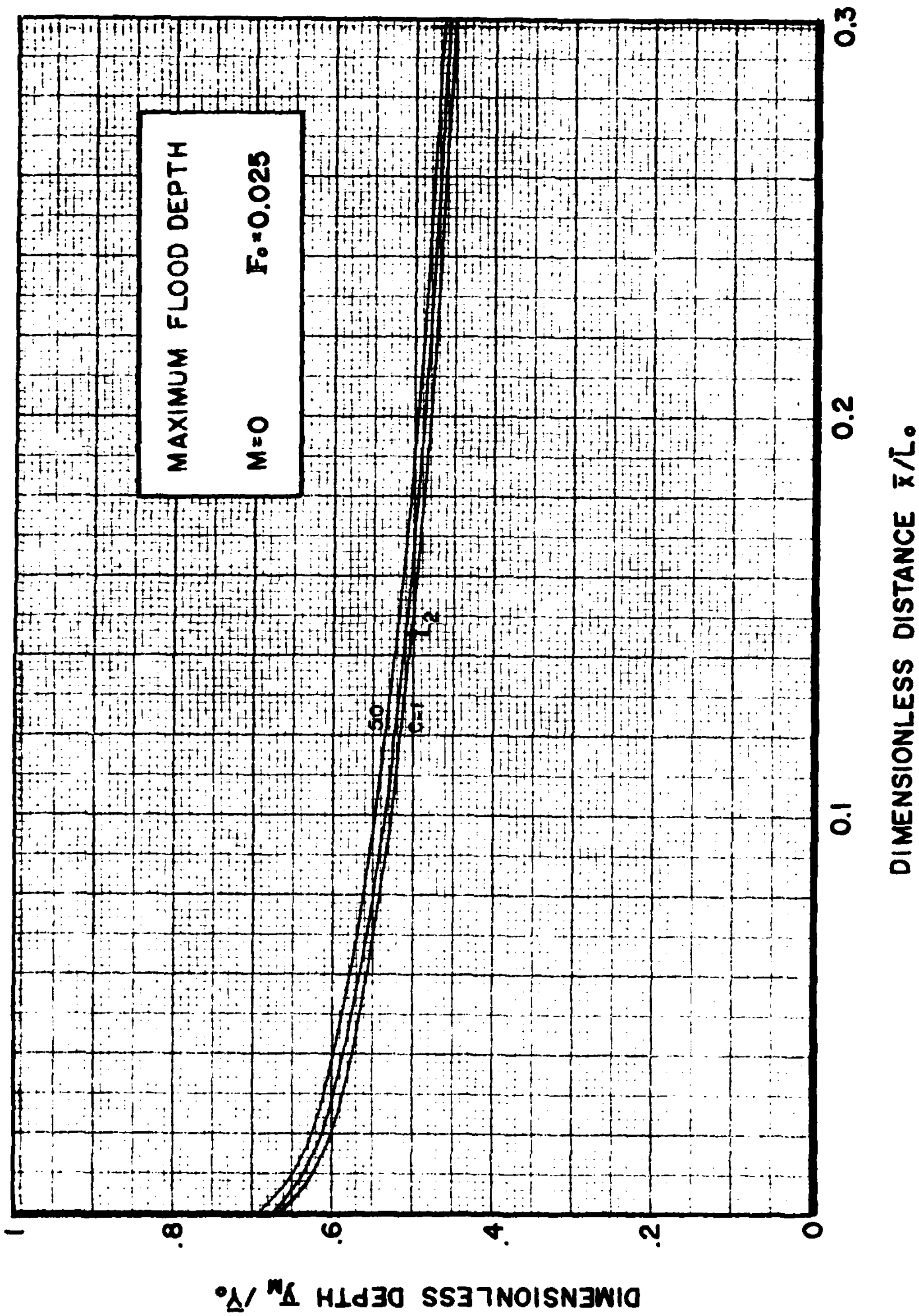

MAXIMUM FLOOD DEPTH
M=0
F_0=0.025
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
DIMENSIONLESS DEPTH Y_M/Y_0
0
0.1
0.2
0.3
.2
.4
.6
.8
1

Fig. B1

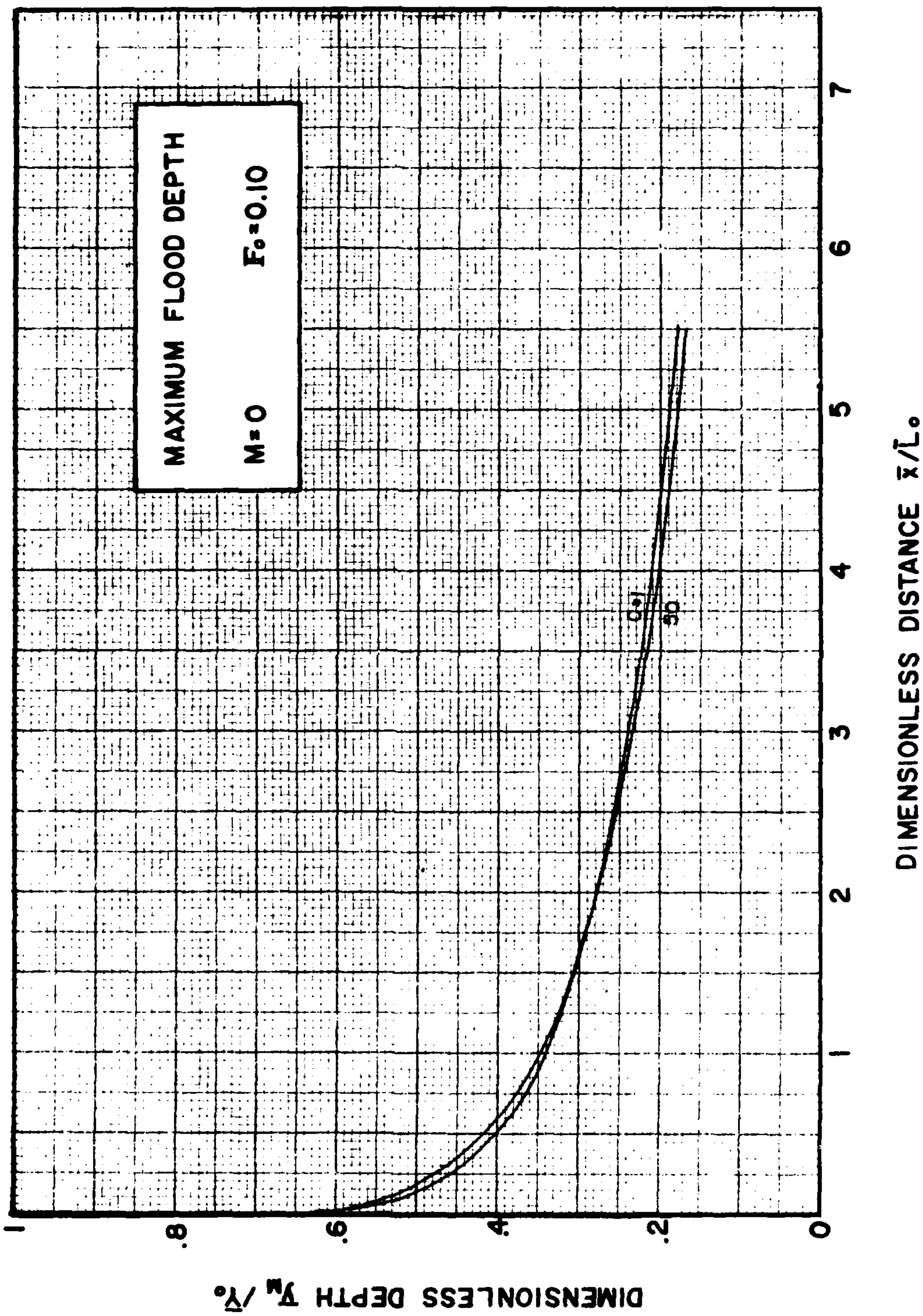

MAXIMUM FLOOD DEPTH
M=0
F_0=0.10
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
DIMENSIONLESS DEPTH $\bar{Y}_m/\bar{Y}_0$
0
1
2
3
4
5
6
7
0
.2
.4
.6
.8
1

Fig. B2

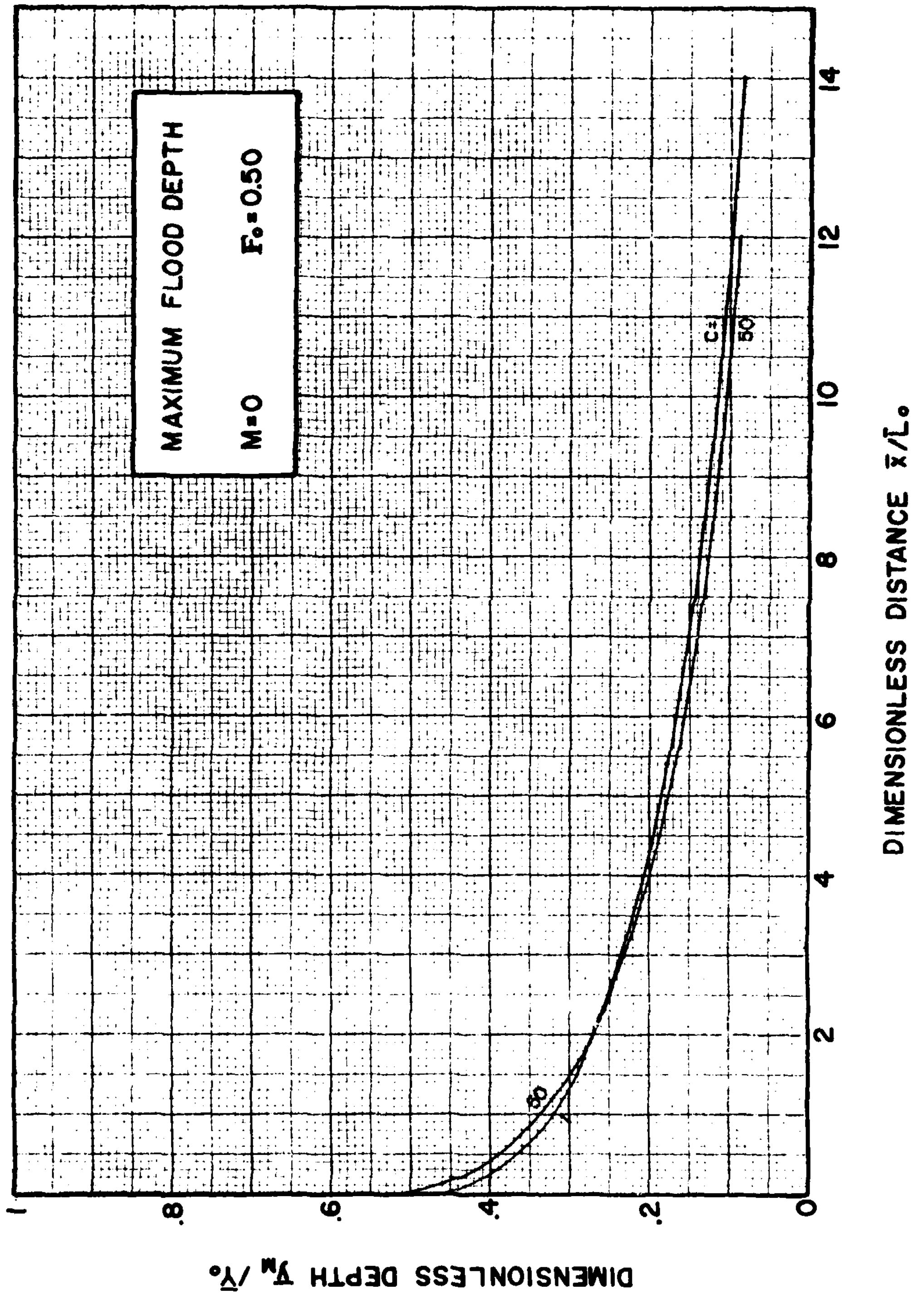
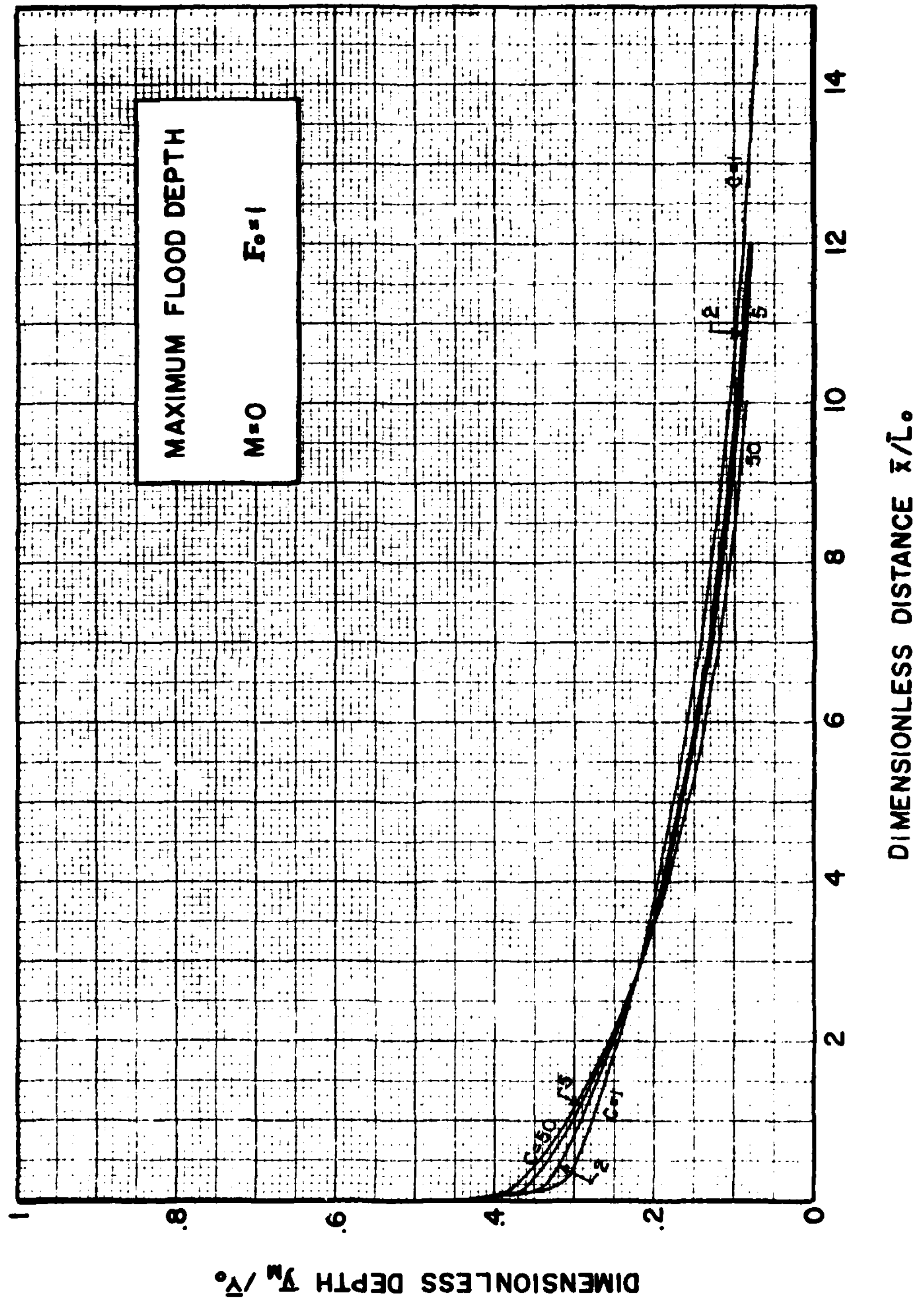
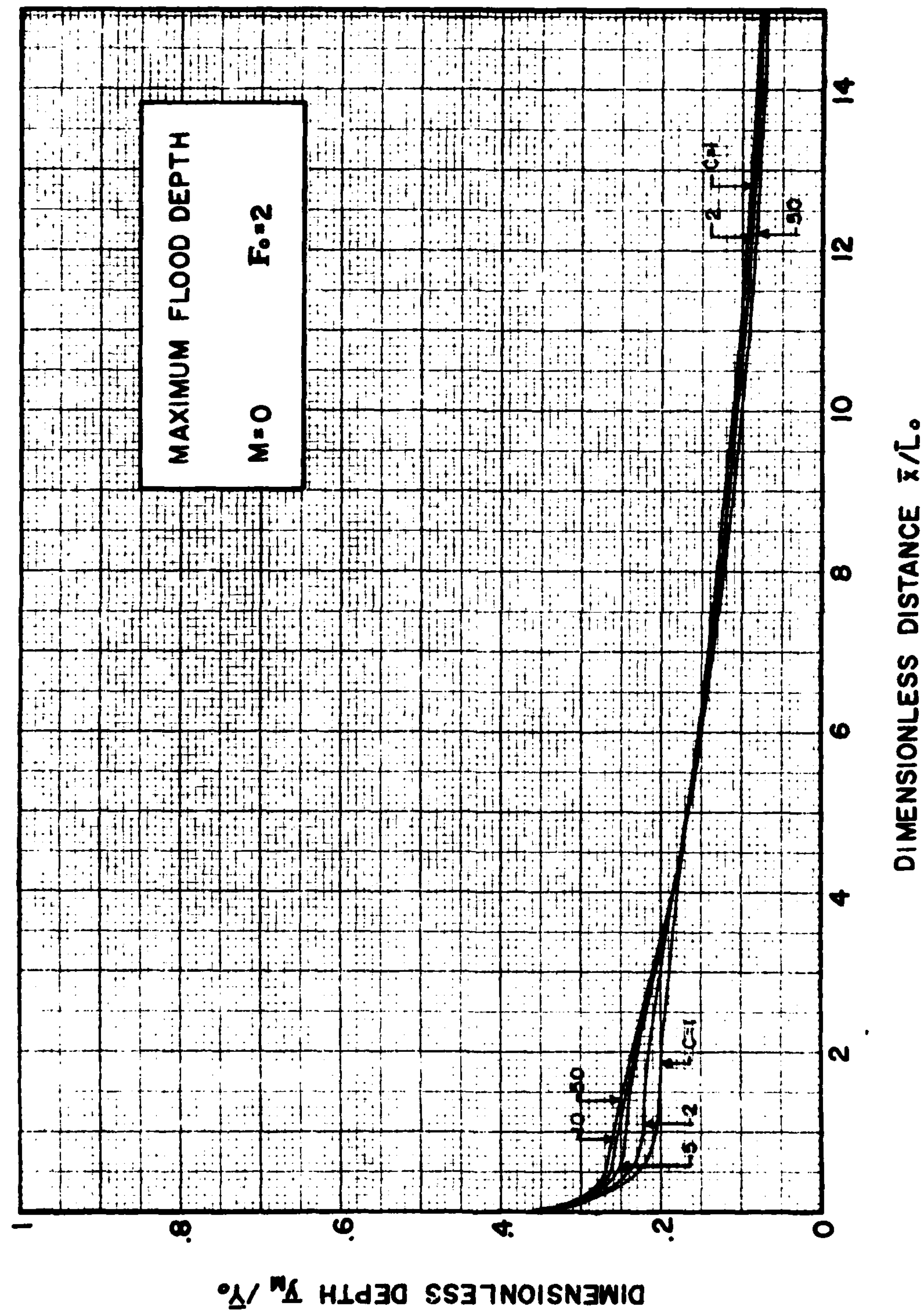

MAXIMUM FLOOD DEPTH
M=O
Fo=0.50
C=1
50
50
DIMENSIONLESS DISTANCE x̄/L̄o
DIMENSIONLESS DEPTH Ym/Yo
0
2
4
6
8
10
12
14
.2
.4
.6
.8
1

Fig. B3



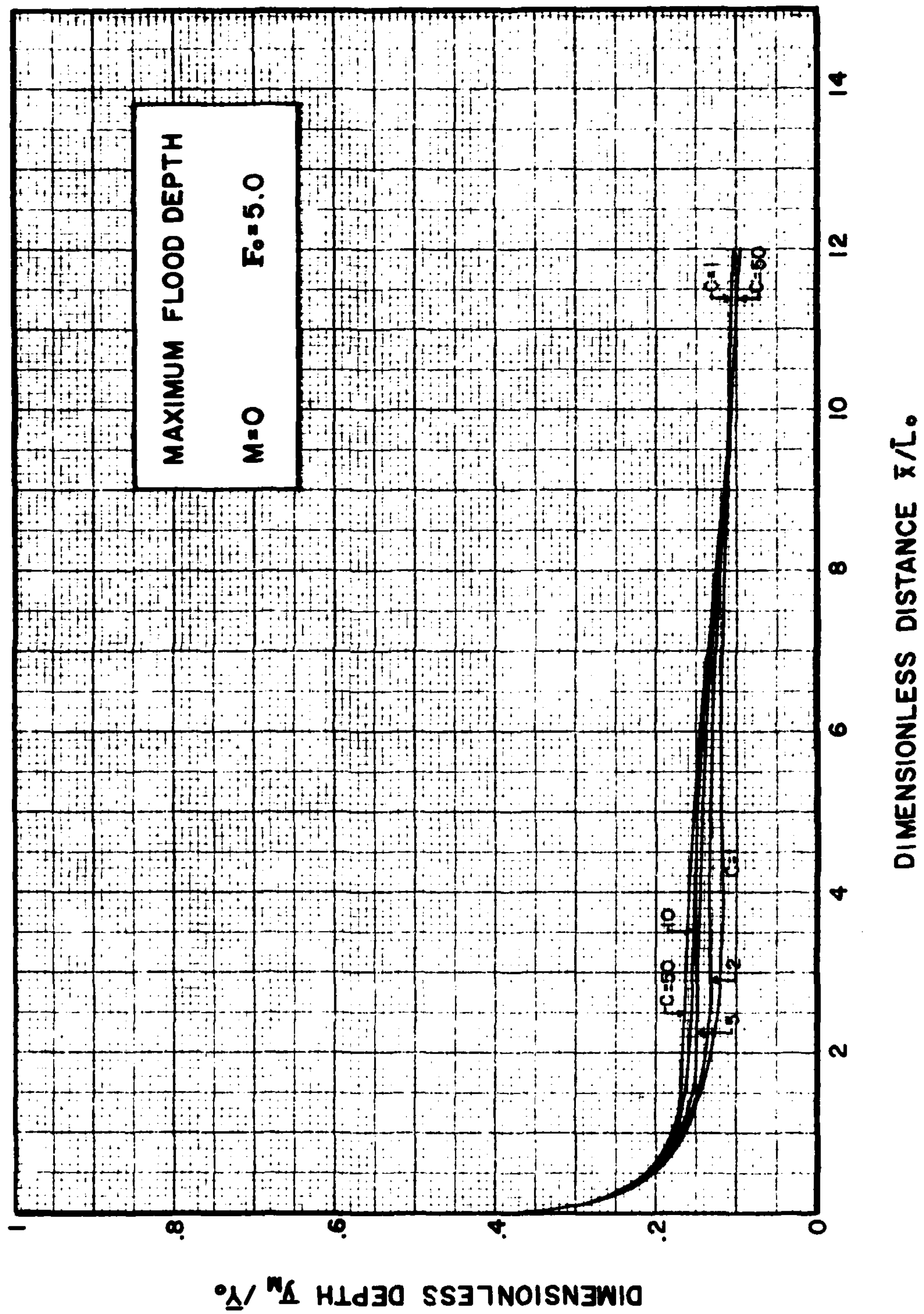
MAXIMUM FLOOD DEPTH
M=0
F₀=1
C=50
C=1
DIMENSIONLESS DISTANCE x̄/L̄₀
DIMENSIONLESS DEPTH ȳ_M/ȳ₀
0
2
4
6
8
10
12
14
.2
.4
.6
.8
1

Fig. B4



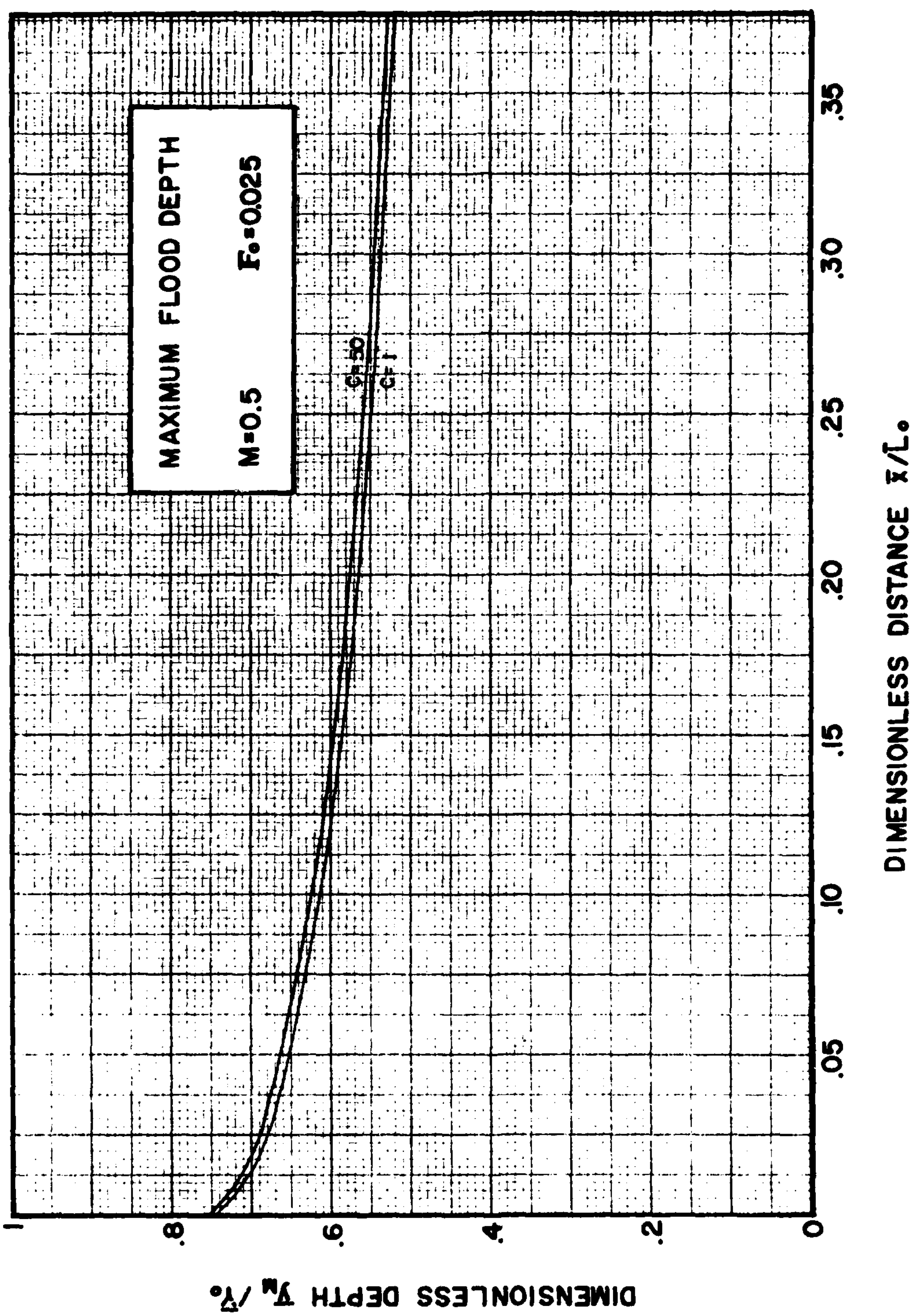
MAXIMUM FLOOD DEPTH
M=0
F₀=2
DIMENSIONLESS DISTANCE x̄/L₀
DIMENSIONLESS DEPTH Y_M/Y₀
0
2
4
6
8
10
12
14
0
.2
.4
.6
.8
1
C=1
2
5
10
30

Fig. B5



MAXIMUM FLOOD DEPTH
M=O
F₀=5.0
C=1
C=50
10
2
.5
DIMENSIONLESS DISTANCE x̄/L̄₀
DIMENSIONLESS DEPTH Ȳₘ/Ȳ₀
0
2
4
6
8
10
12
14
.2
.4
.6
.8
1

Fig. B6



MAXIMUM FLOOD DEPTH
M=0.5
F_o=0.025
C=50
C=1
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
DIMENSIONLESS DEPTH Y_m/Y_o
.05
.10
.15
.20
.25
.30
.35
0
.2
.4
.6
.8
1

Fig. B7

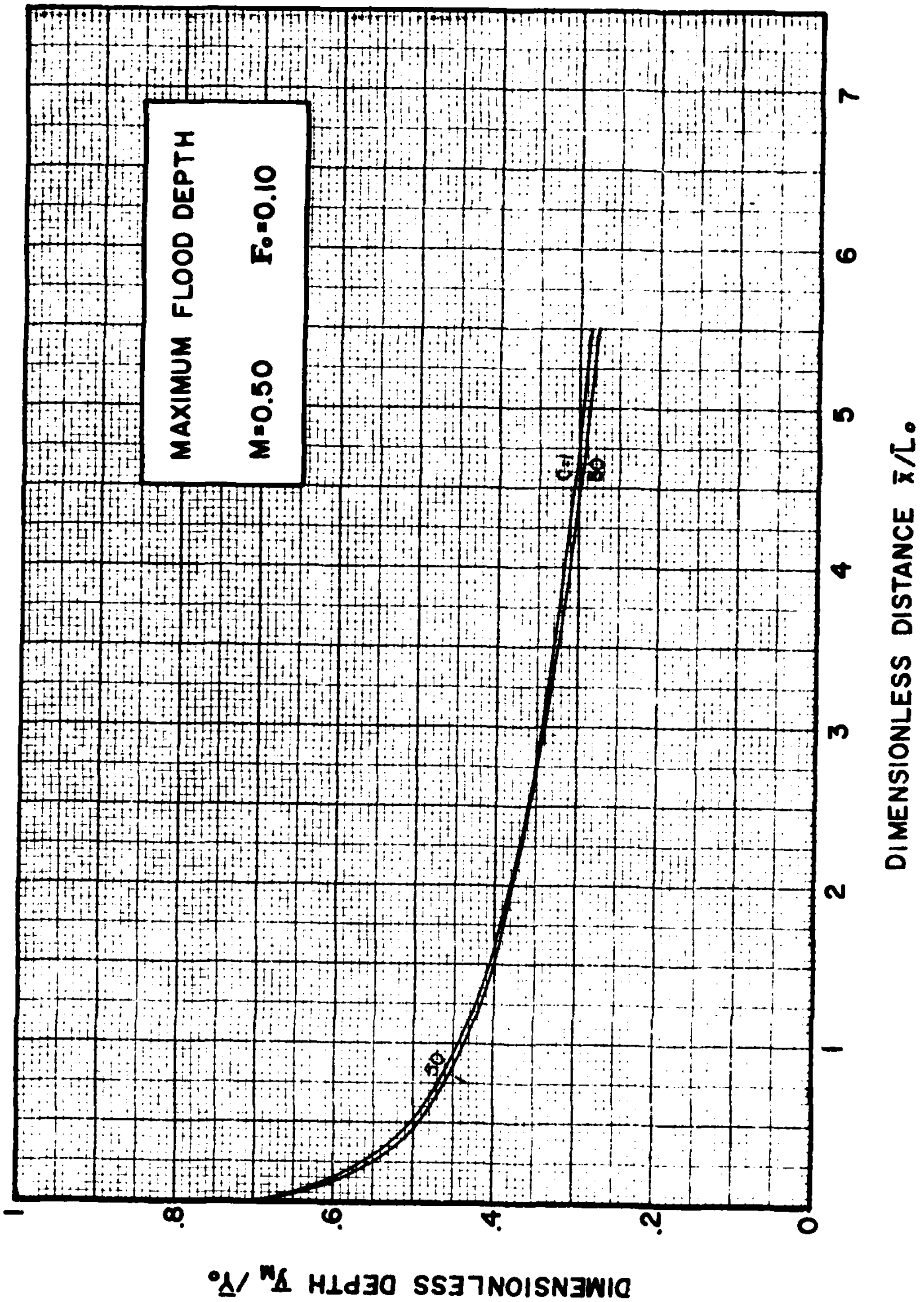

MAXIMUM FLOOD DEPTH
M=0.50
F₀=0.10
DIMENSIONLESS DISTANCE x̄/L₀
DIMENSIONLESS DEPTH Y_M/Y₀

Fig. B8

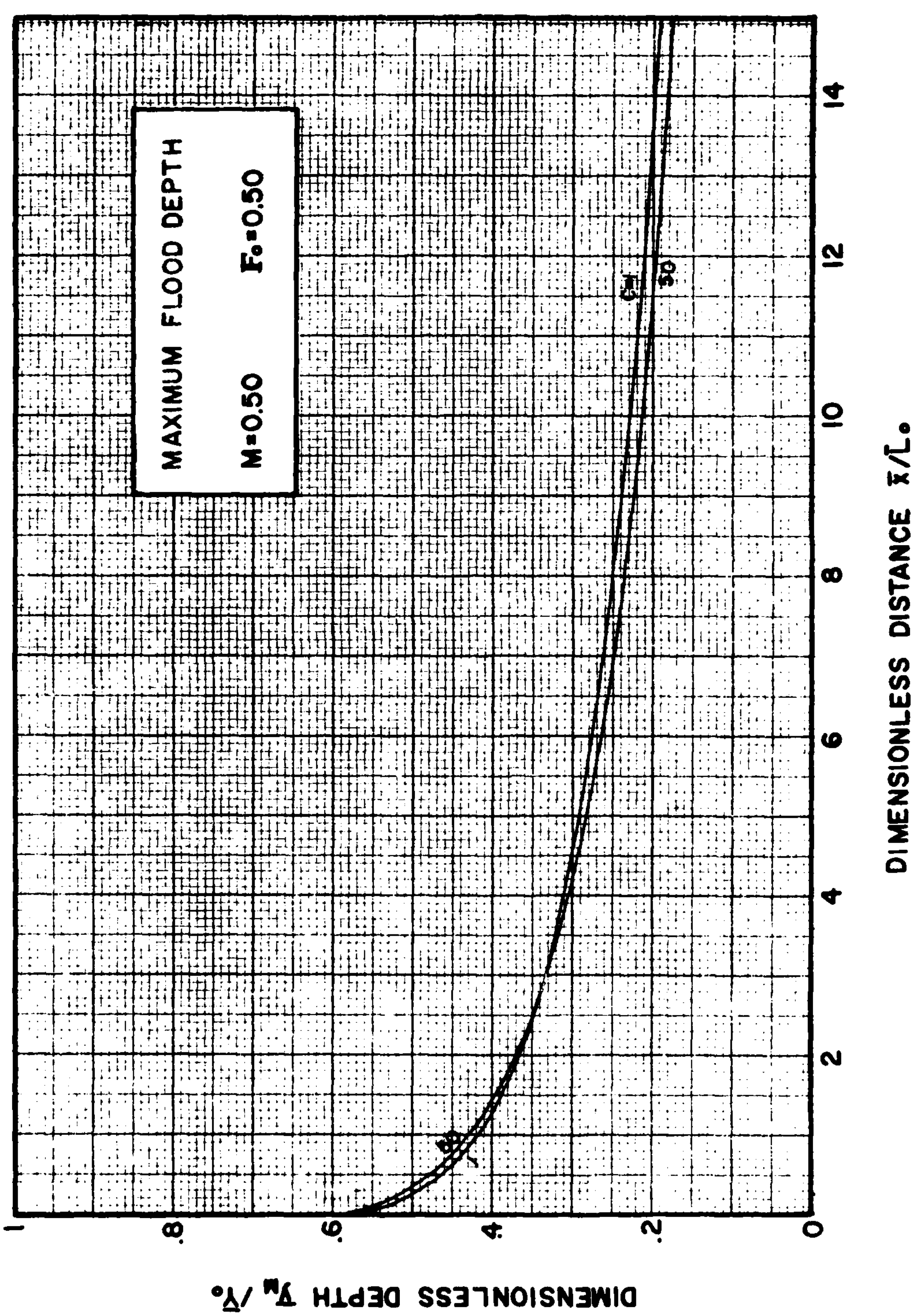
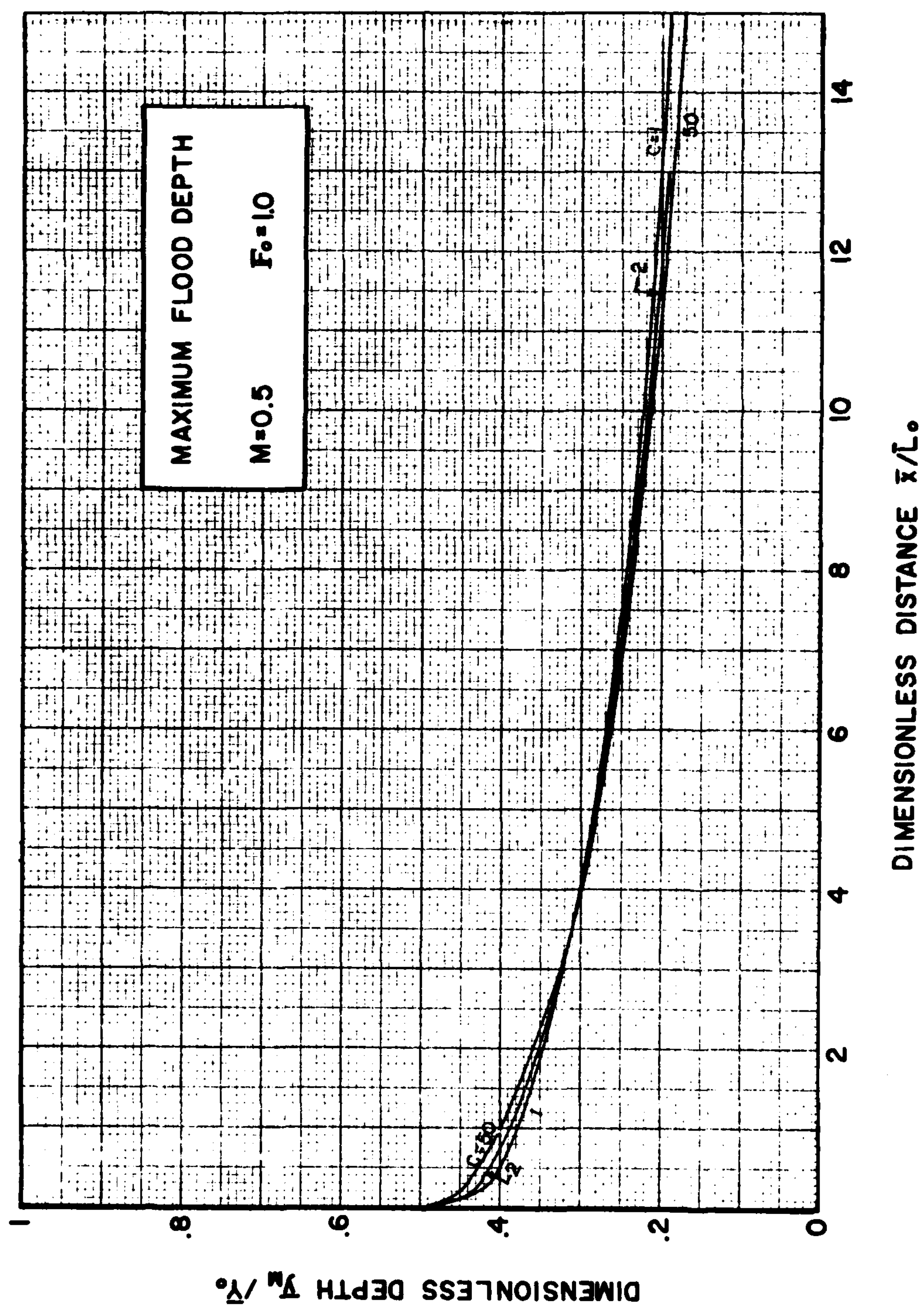

MAXIMUM FLOOD DEPTH
M=0.50
F₀=0.50
DIMENSIONLESS DISTANCE x̄/L₀
DIMENSIONLESS DEPTH Y_M/Y₀
0
2
4
6
8
10
12
14
.2
.4
.6
.8
1

Fig. B9



MAXIMUM FLOOD DEPTH
M=0.5
Fo=1.0
DIMENSIONLESS DISTANCE x̄/Lo
DIMENSIONLESS DEPTH Ym/Yo

Fig. B10

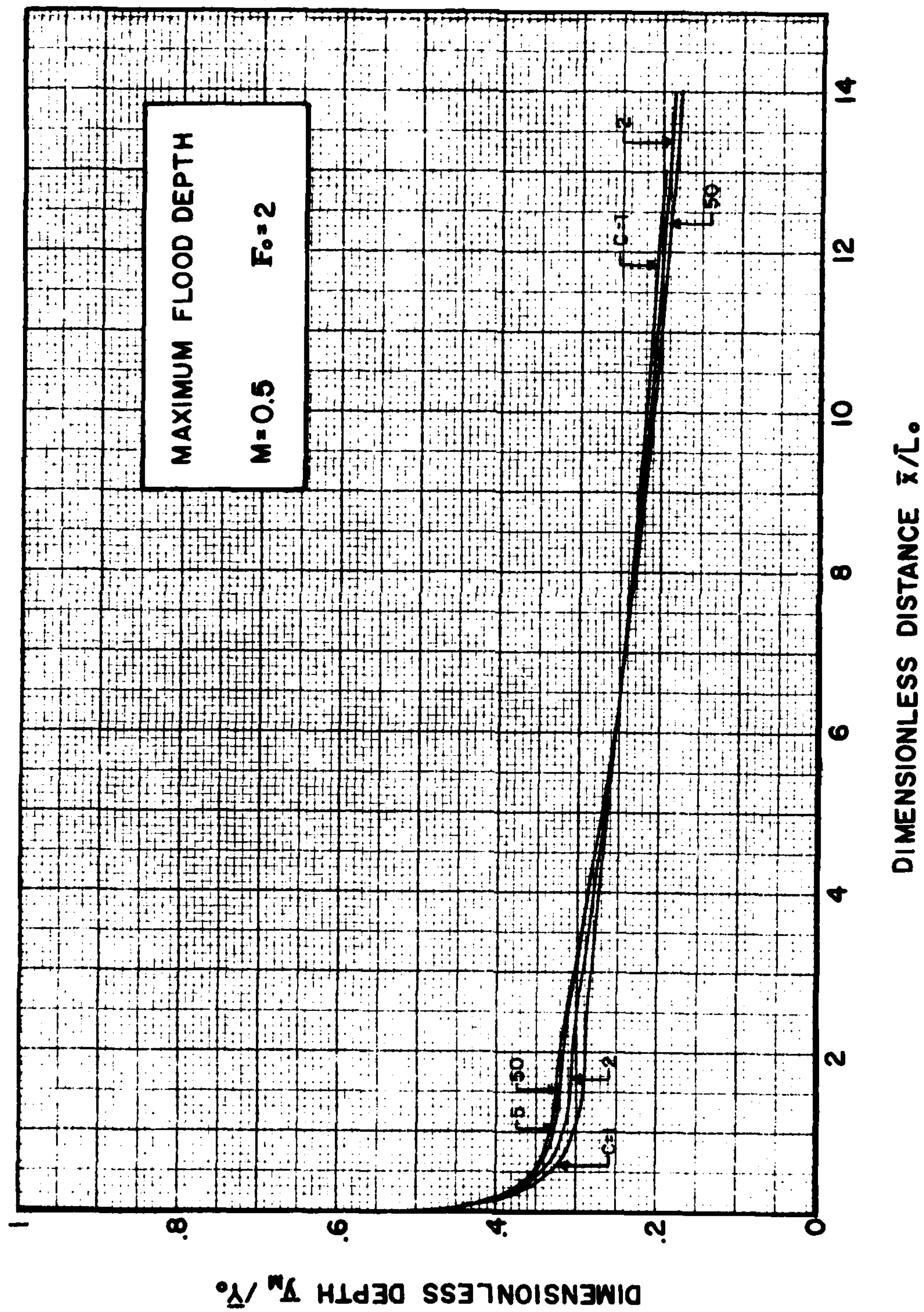

MAXIMUM FLOOD DEPTH
M=0.5
F_o=2
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
DIMENSIONLESS DEPTH $\bar{Y}_M/\bar{Y}_o$
0
2
4
6
8
10
12
14
.2
.4
.6
.8
1
C=
.5
50
2
C=1
50
2

Fig. B11

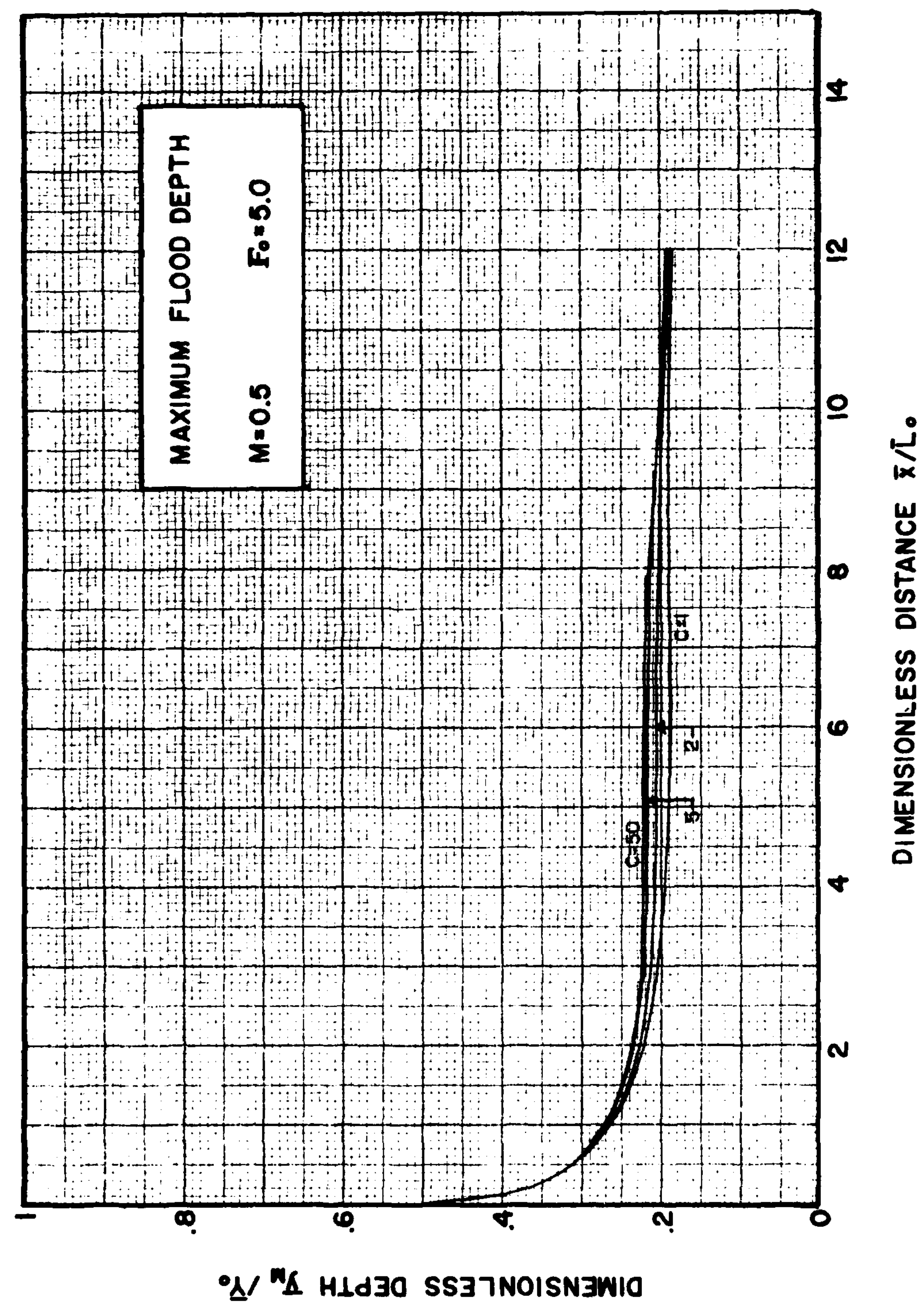

MAXIMUM FLOOD DEPTH
M=0.5
F_o=5.0
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
DIMENSIONLESS DEPTH $\bar{Y}_M/\bar{Y}_o$
C=50
0
2
4
6
8
10
12
14
.2
.4
.6
.8
1

Fig. B12

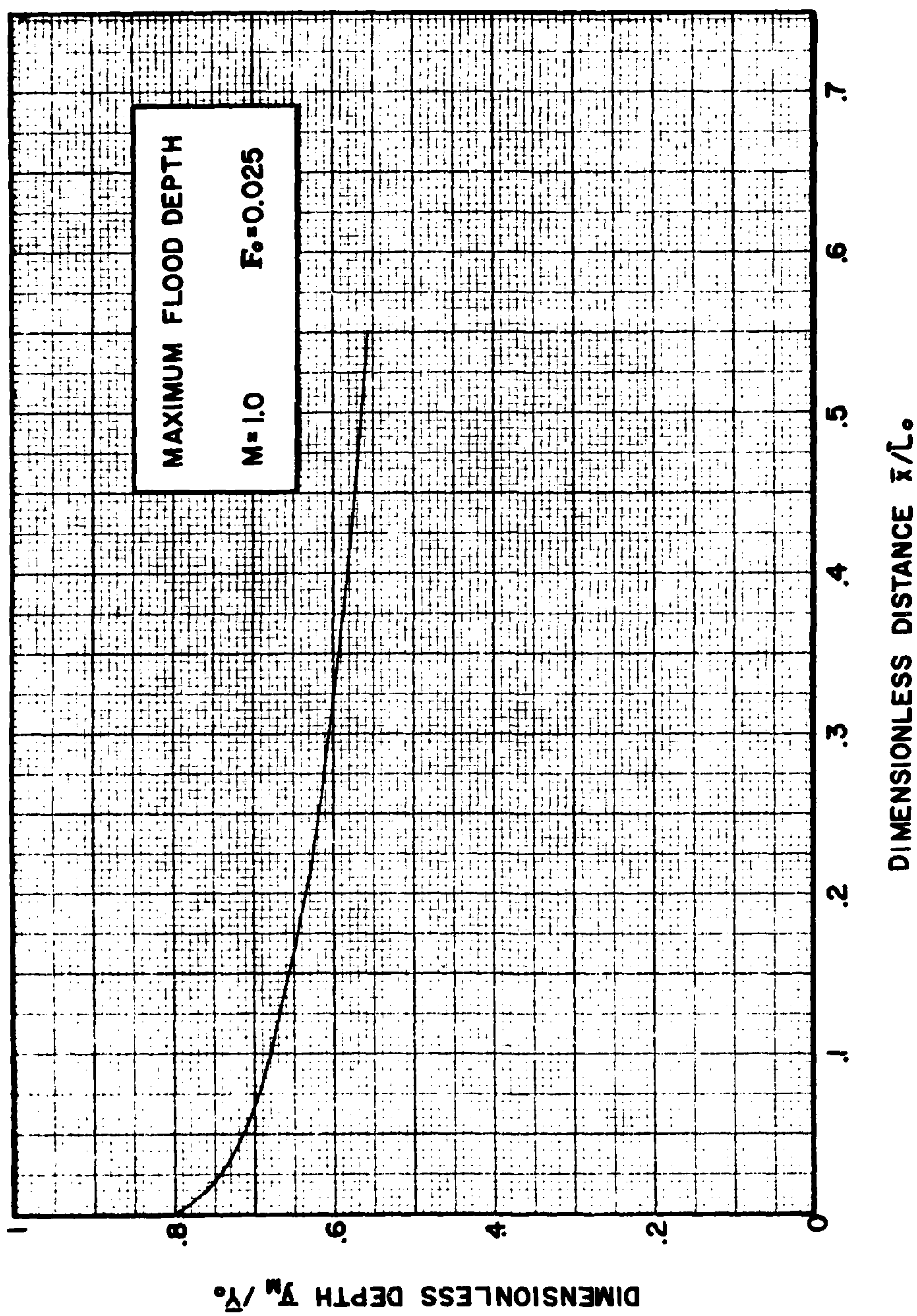

MAXIMUM FLOOD DEPTH
M=1.0
F₀=0.025
DIMENSIONLESS DISTANCE x̄/L̄₀
DIMENSIONLESS DEPTH Ȳm/Ȳ₀
0
.1
.2
.3
.4
.5
.6
.7
.2
.4
.6
.8
1

Fig. B13

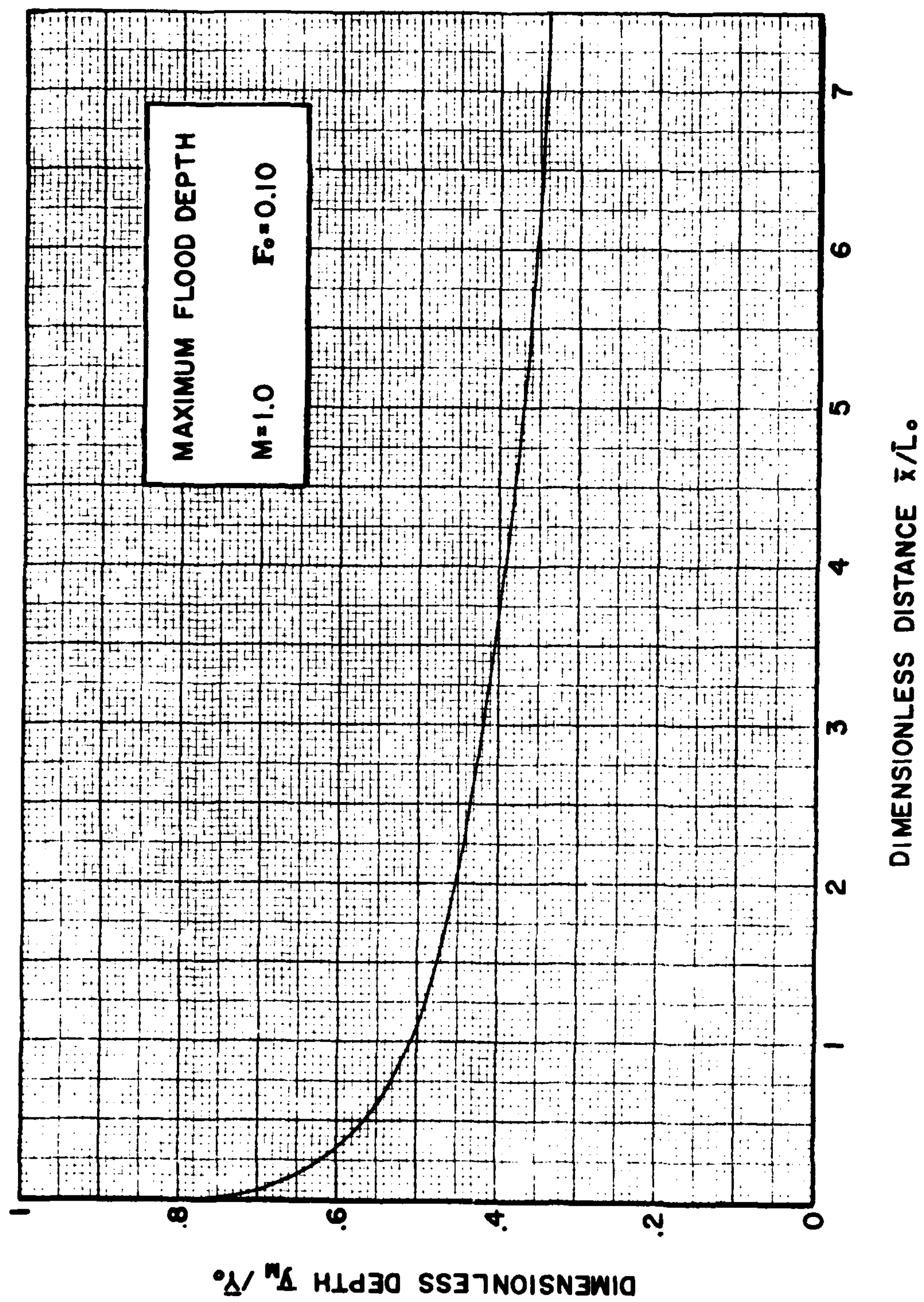
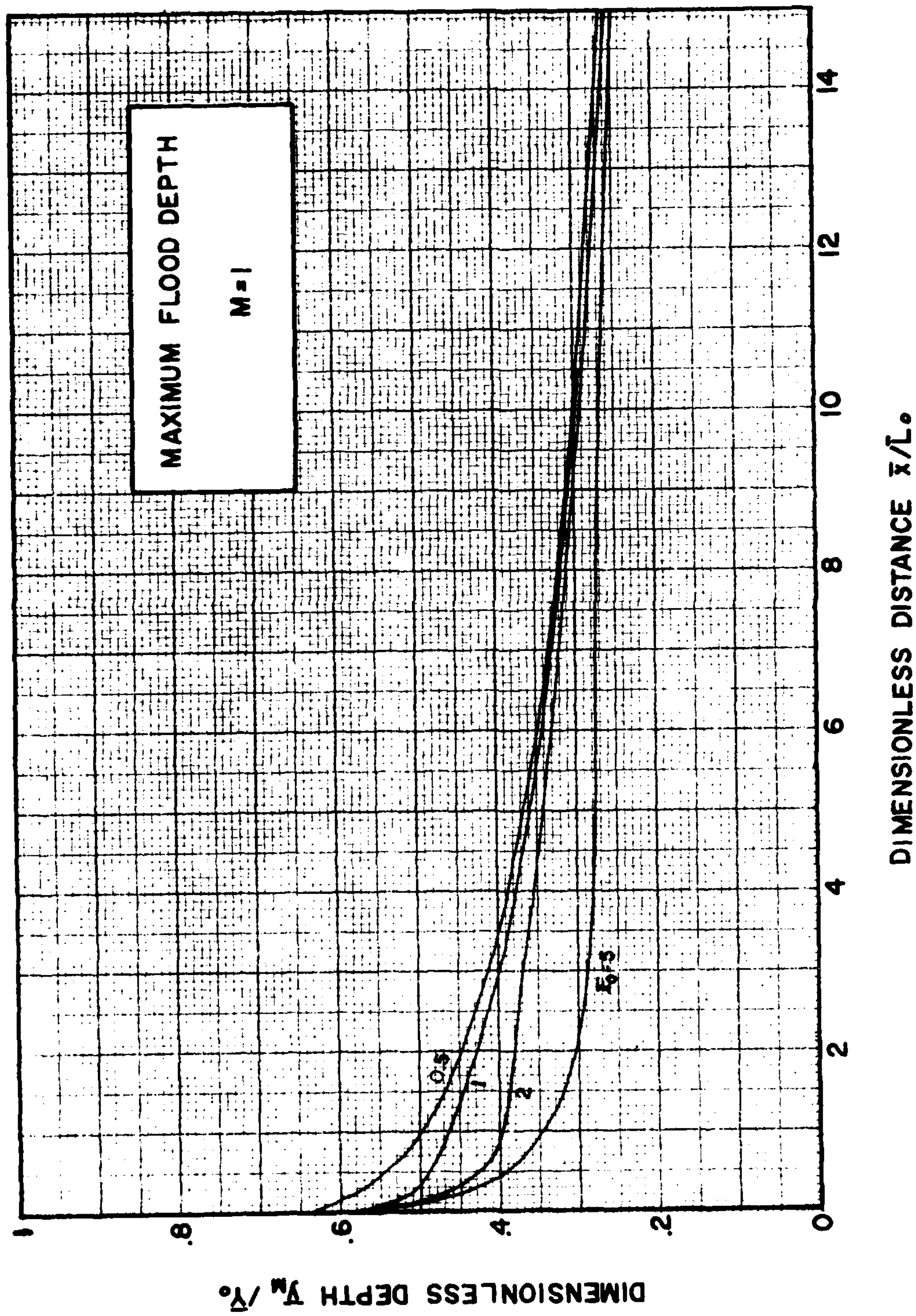

MAXIMUM FLOOD DEPTH
M=1.0
F₀=0.10
DIMENSIONLESS DISTANCE x̄/L̄₀
DIMENSIONLESS DEPTH Y_M/Y₀
0
1
2
3
4
5
6
7
0
.2
.4
.6
.8
1

Fig. B14



MAXIMUM FLOOD DEPTH
M=1
DIMENSIONLESS DISTANCE $\bar{x}/L_o$
DIMENSIONLESS DEPTH Y_m/Y_o
0.5
1
2
0
2
4
6
8
10
12
14
1
.8
.6
.4
.2
0

Fig. B15

APPENDIX C

GRAPHS FOR
THE TIME OF OCCURRENCE OF MAXIMUM FLOOD LEVEL

(Figs. C1 to C15)

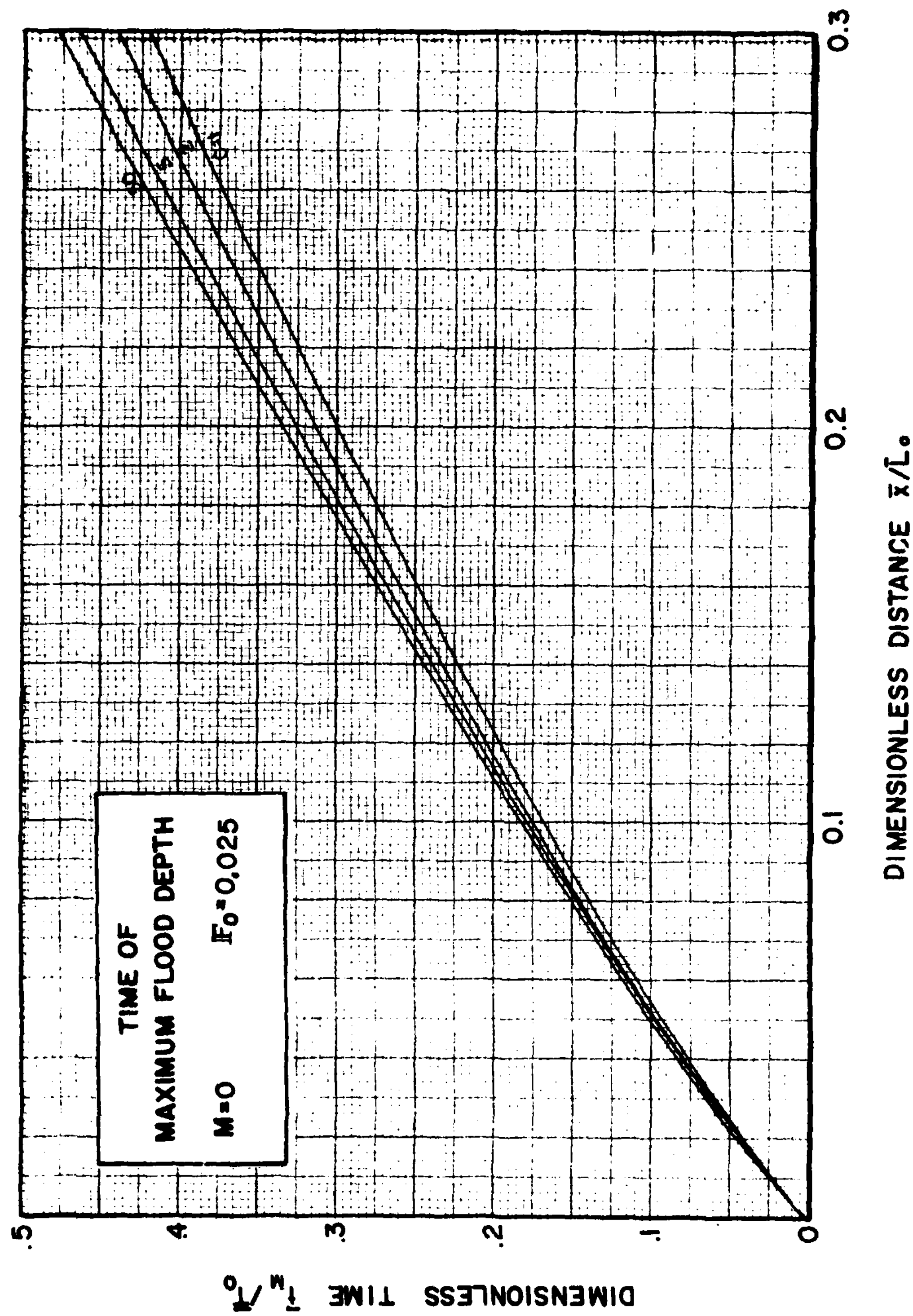

TIME OF
MAXIMUM FLOOD DEPTH
M=0
F_0=0.025
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_o$
DIMENSIONLESS TIME T_M/T_0
0
.1
.2
.3
.4
.5
0.1
0.2
0.3

Fig. C1

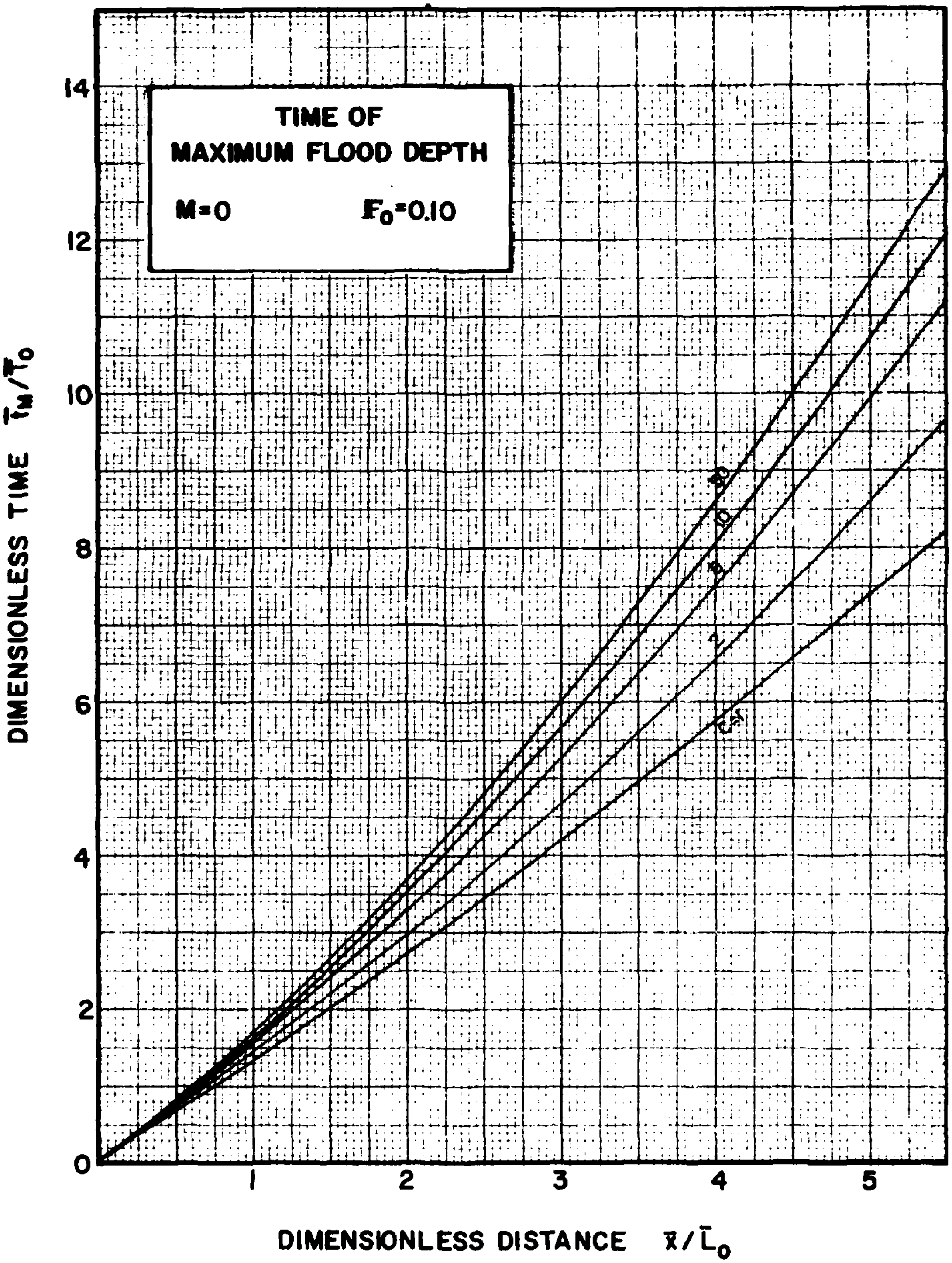

TIME OF
MAXIMUM FLOOD DEPTH
M=0
F0=0.10
DIMENSIONLESS TIME
DIMENSIONLESS DISTANCE
0
2
4
6
8
10
12
14
1
2
3
4
5

Fig. C2

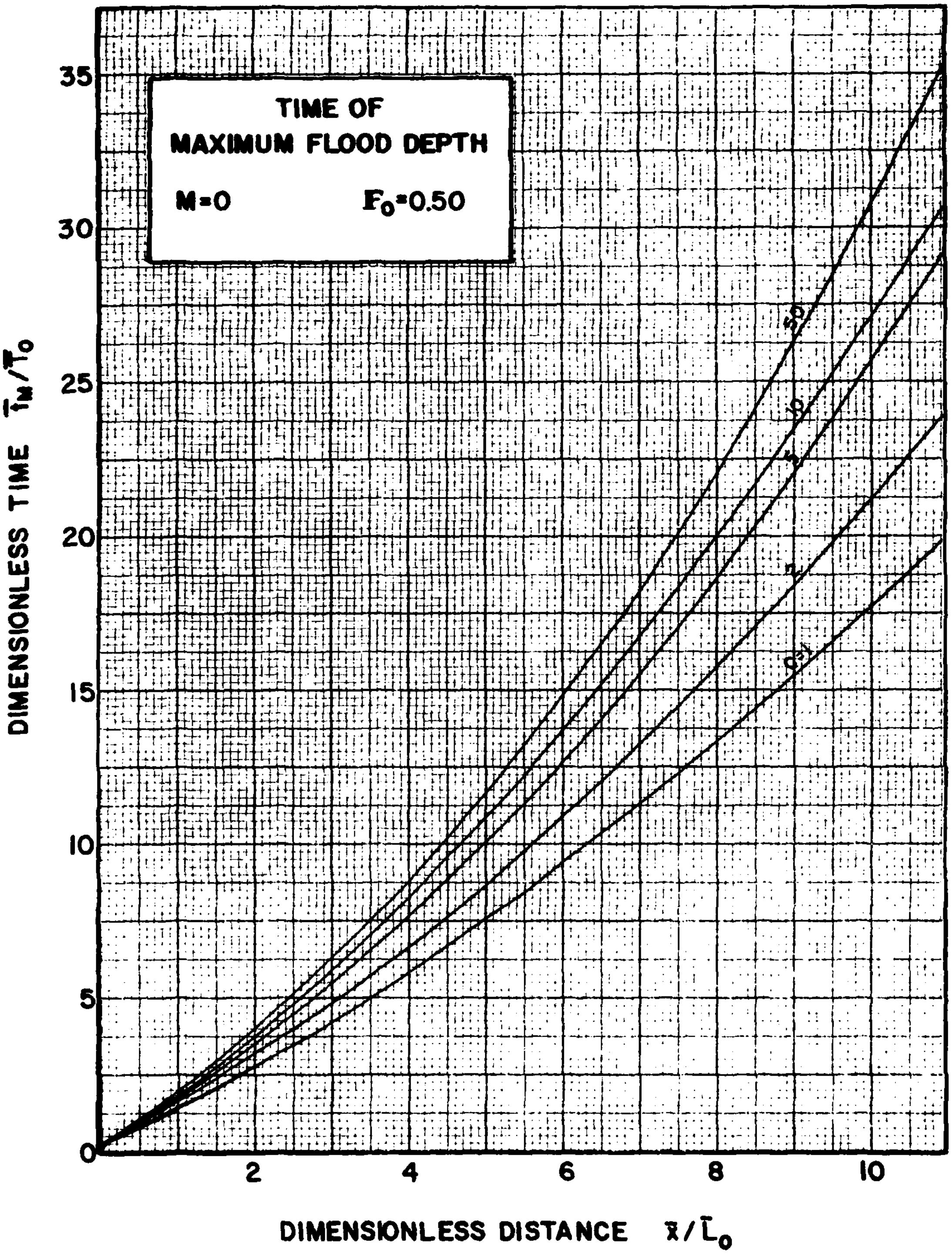

TIME OF
MAXIMUM FLOOD DEPTH
M=0
F_0=0.50
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{X}/\bar{L}_0$
0
5
10
15
20
25
30
35
2
4
6
8
10

Fig. C3

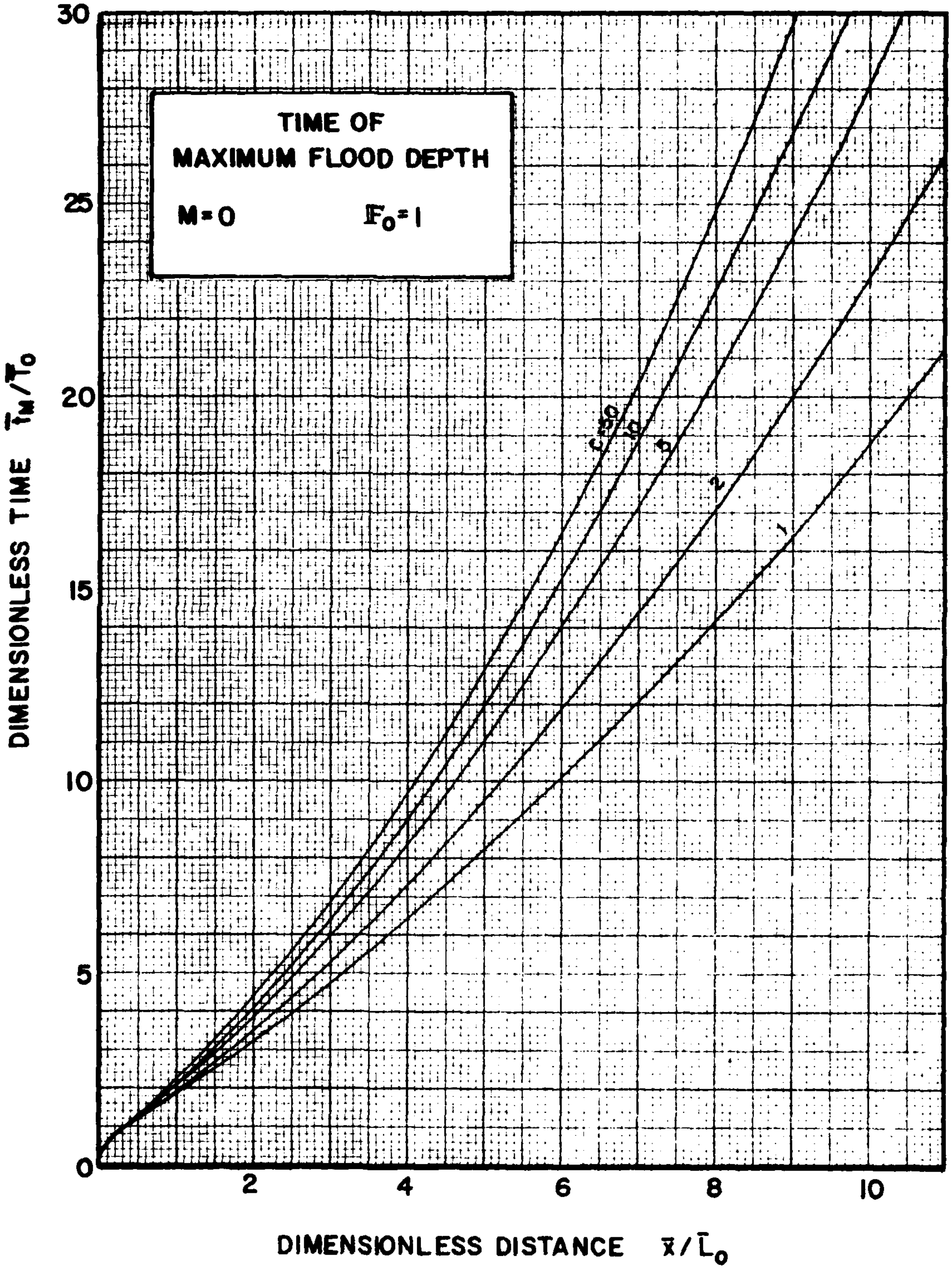

TIME OF
MAXIMUM FLOOD DEPTH
M=0
$\mathbb{F}_0$=1
DIMENSIONLESS TIME $\bar{t}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
0
5
10
15
20
25
30
2
4
6
8
10
C=20
10
5
2
1

Fig. C4

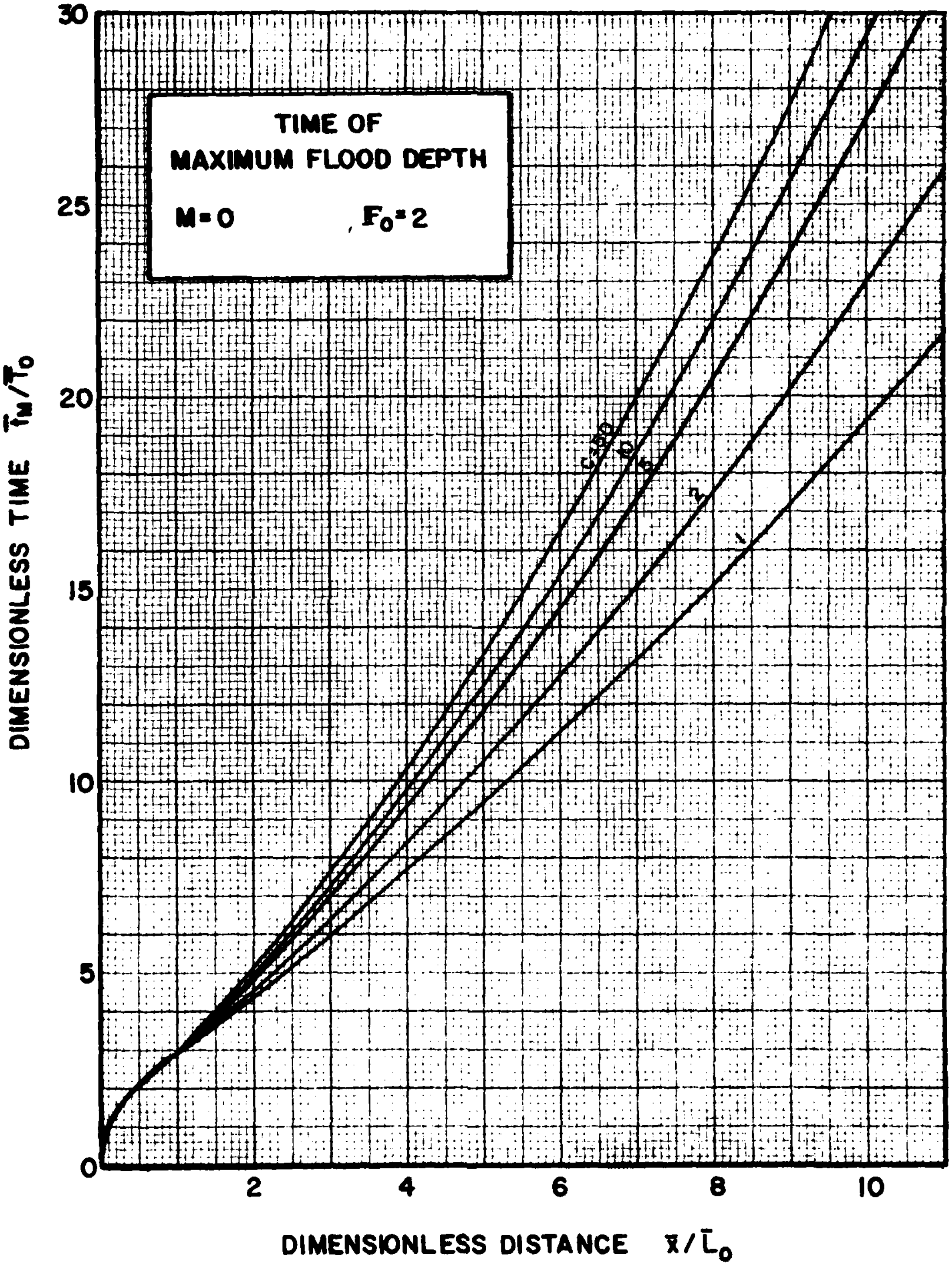

TIME OF
MAXIMUM FLOOD DEPTH
M=0
F0=2
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{X}/\bar{L}_0$
0
5
10
15
20
25
30
2
4
6
8
10
C=50
10
5
2
1

Fig. C5

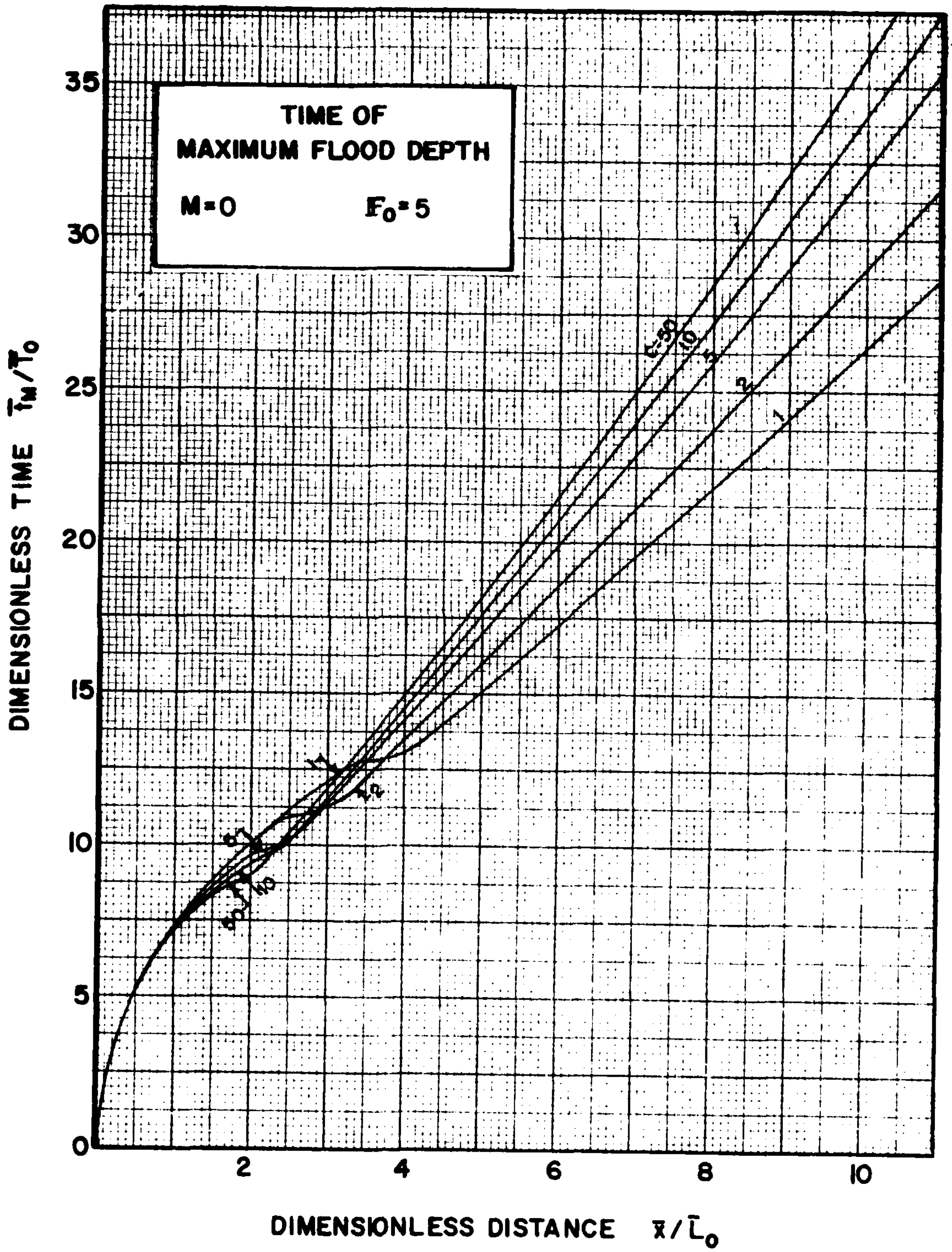

TIME OF
MAXIMUM FLOOD DEPTH
M=0
F0=5
DIMENSIONLESS TIME T̄M/T̄o
DIMENSIONLESS DISTANCE x̄/L̄o
c=50
10
5
2
1
0
5
10
15
20
25
30
35
2
4
6
8
10

Fig. C6

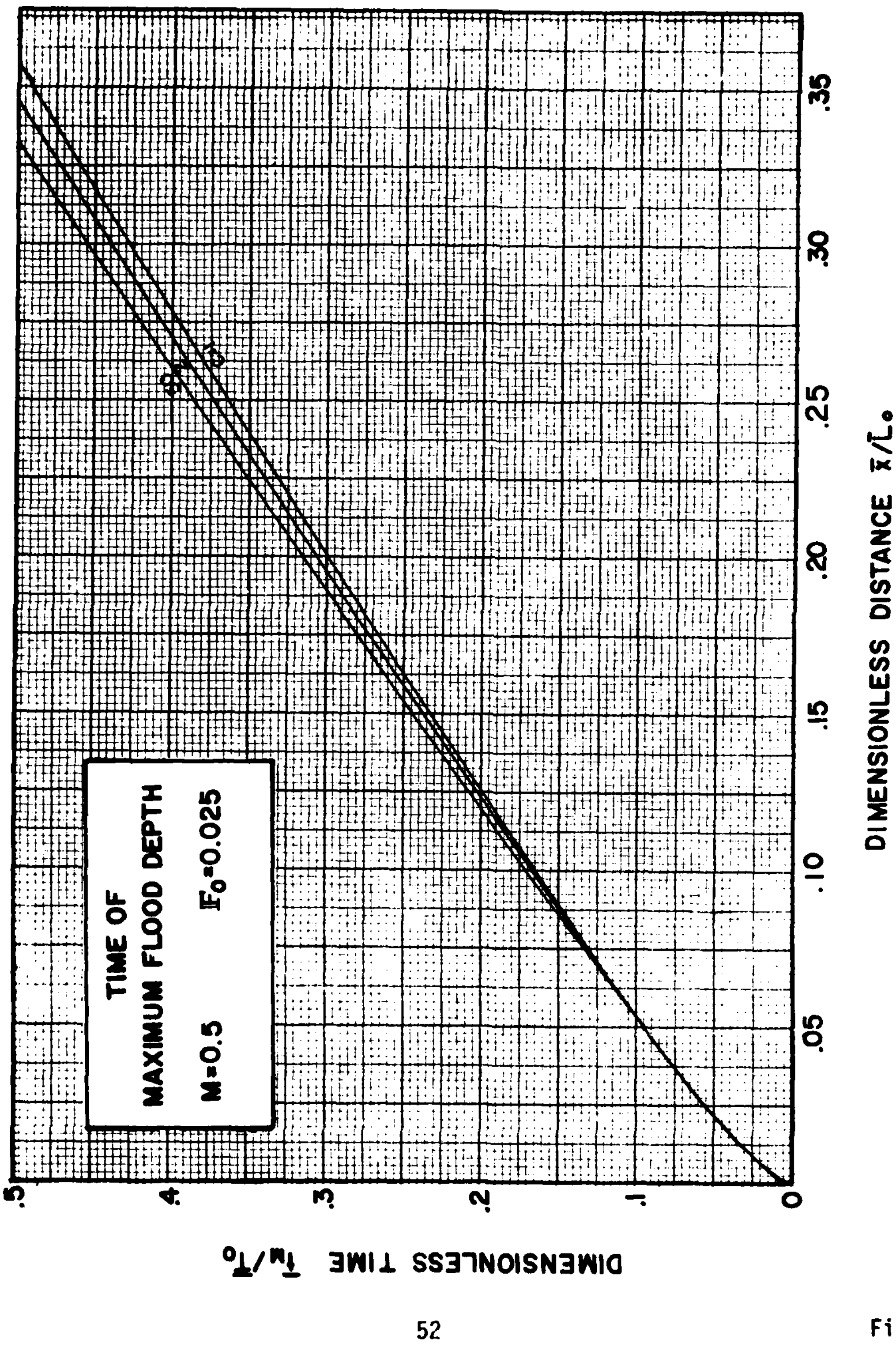

TIME OF
MAXIMUM FLOOD DEPTH
M=0.5
F₀=0.025
DIMENSIONLESS DISTANCE x̄/L̄₀
DIMENSIONLESS TIME t̄ₘ/T̄₀
0
.05
.10
.15
.20
.25
.30
.35
.1
.2
.3
.4
.5

Fig. C7

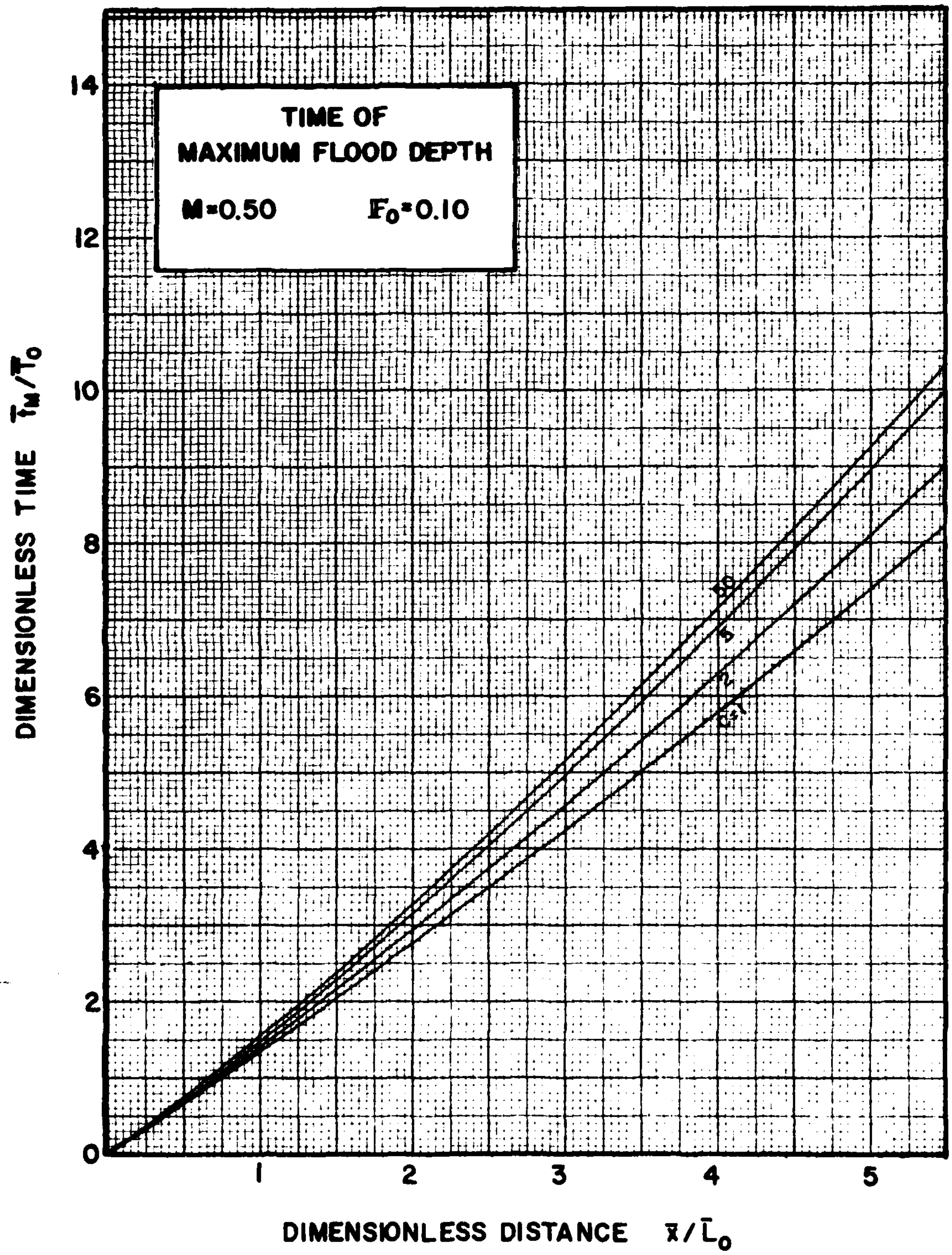

TIME OF
MAXIMUM FLOOD DEPTH
M=0.50
F_0=0.10
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
0
2
4
6
8
10
12
14
1
2
3
4
5

Fig. C8

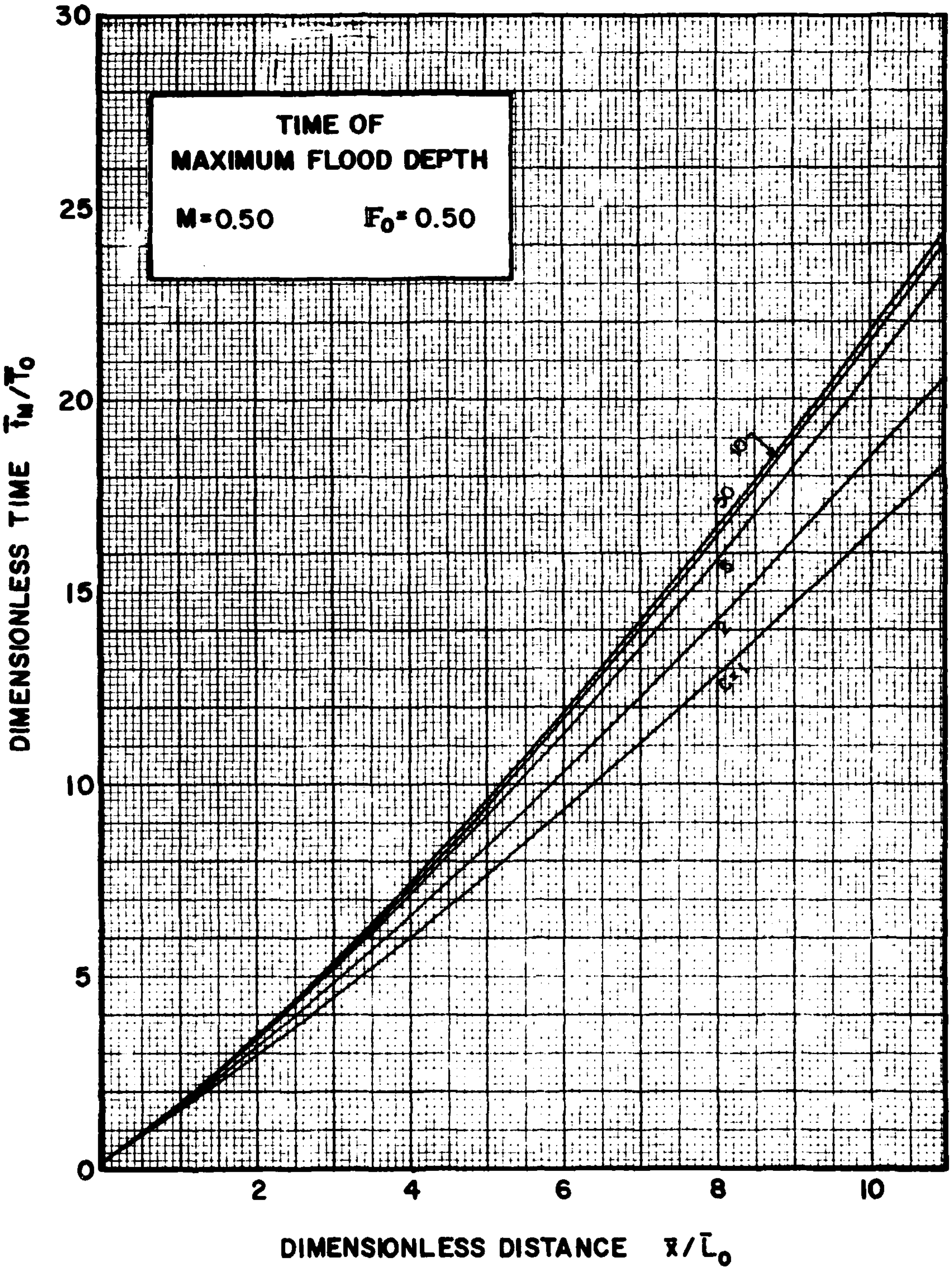

TIME OF
MAXIMUM FLOOD DEPTH
M=0.50
F0= 0.50
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{X}/\bar{L}_0$
0
5
10
15
20
25
30
2
4
6
8
10

Fig. C9

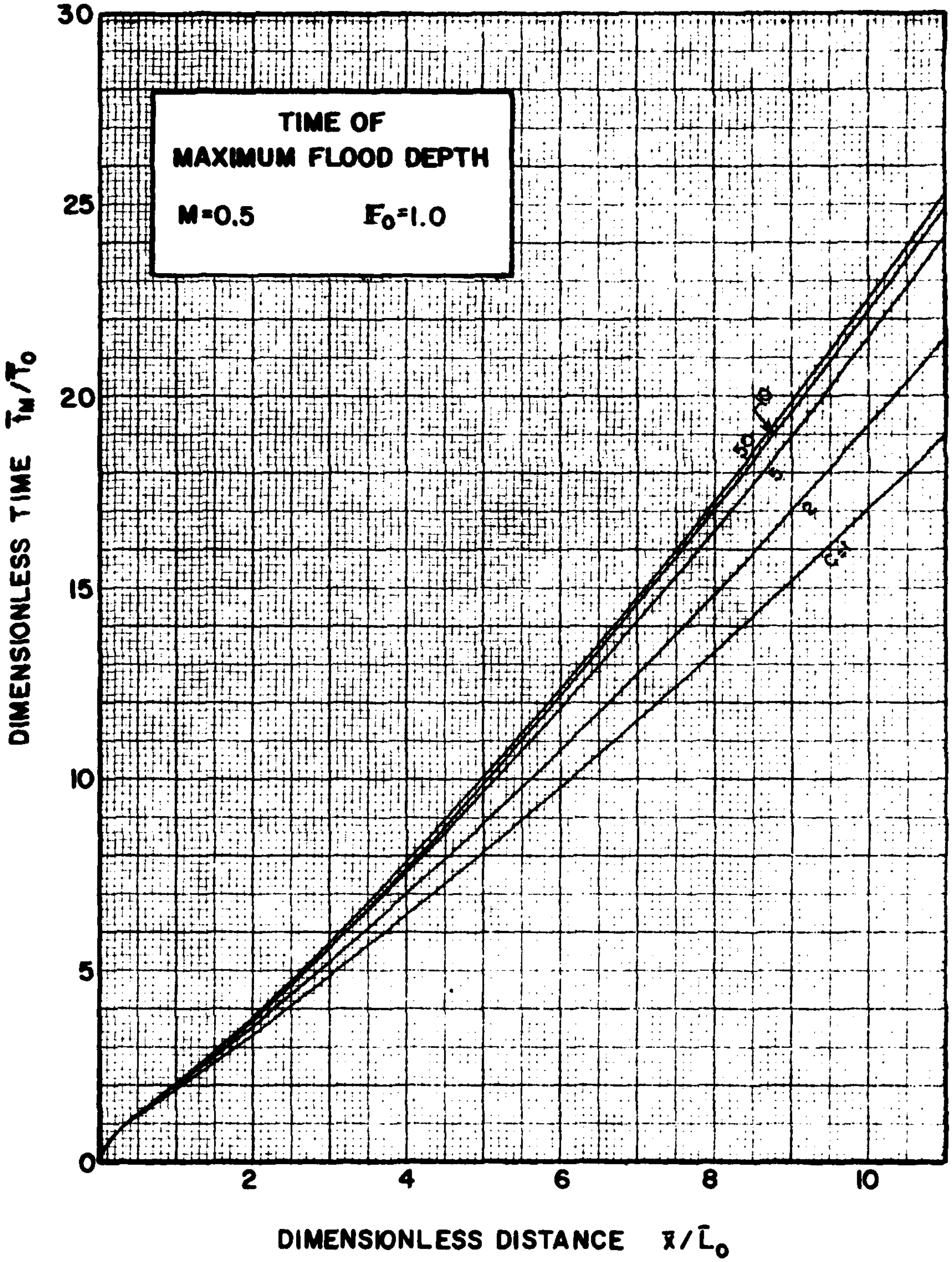

TIME OF
MAXIMUM FLOOD DEPTH
M=0.5
F_0=1.0
30
25
20
15
10
5
0
2
4
6
8
10
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{X}/\bar{L}_0$
10
30
5
2

Fig. C10

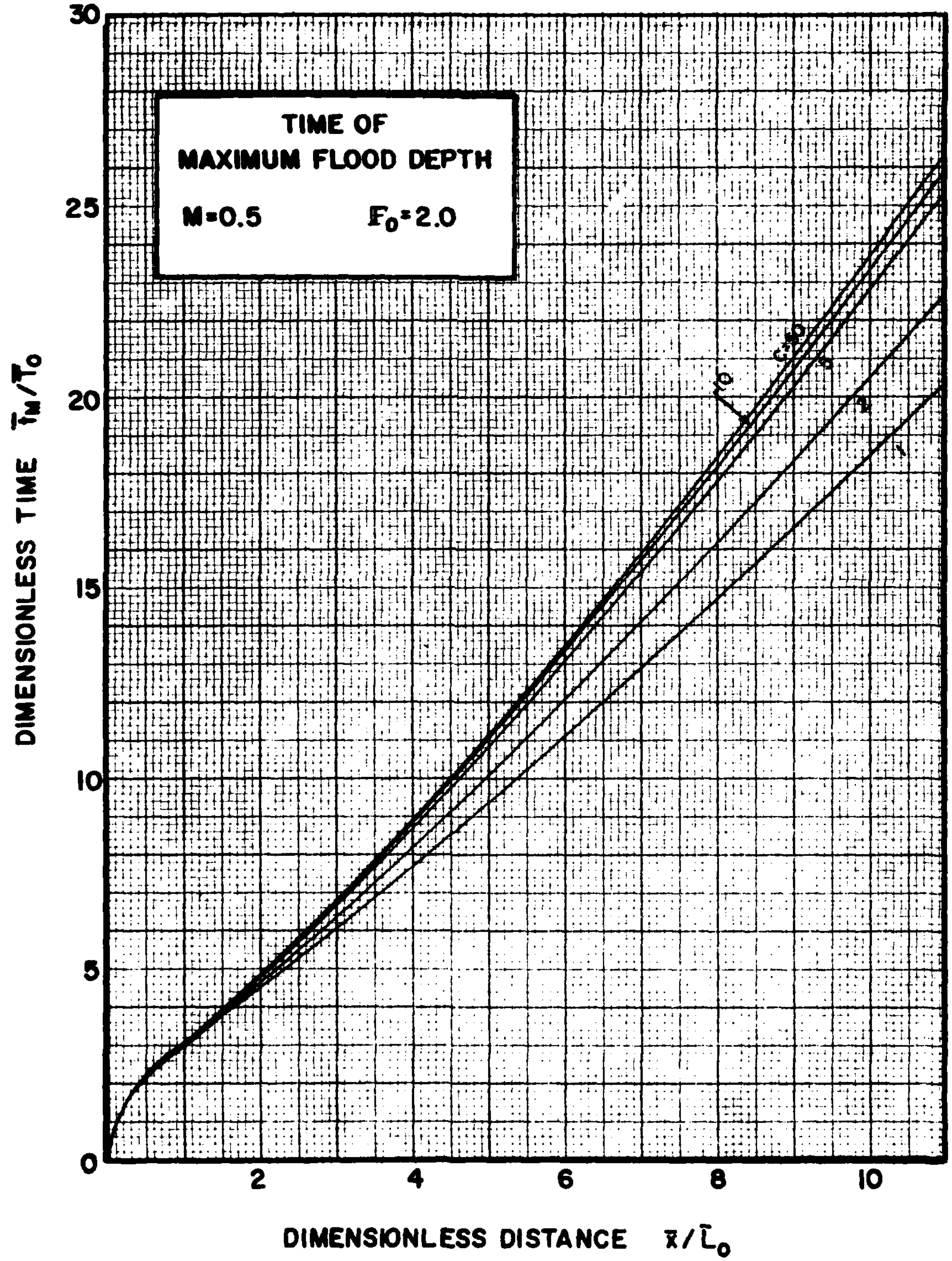

TIME OF
MAXIMUM FLOOD DEPTH
M=0.5
$\mathbb{F}_0$=2.0
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
0
5
10
15
20
25
30
2
4
6
8
10

Fig. C11

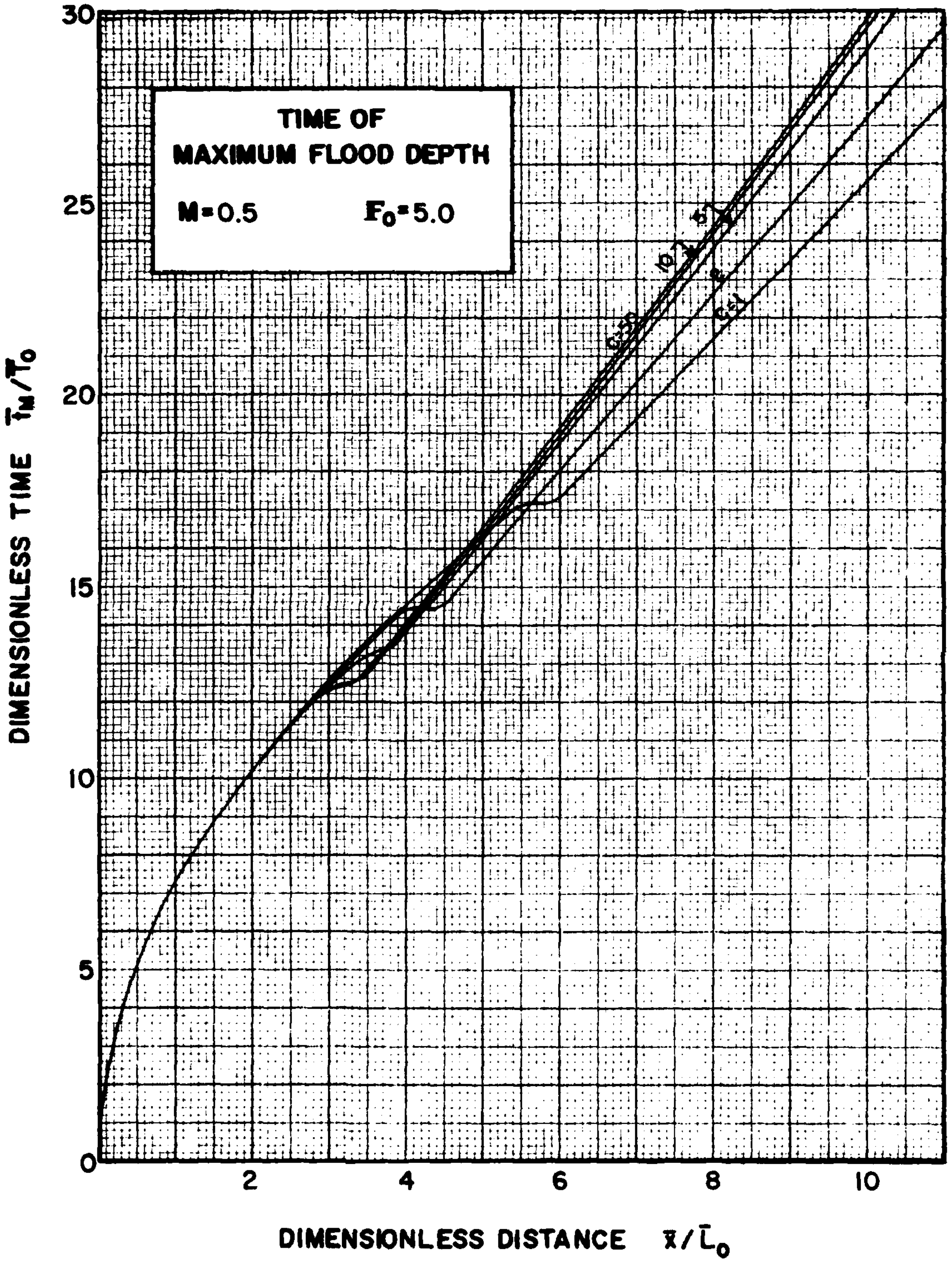

TIME OF
MAXIMUM FLOOD DEPTH
M=0.5 F0=5.0
30
25
20
15
10
5
0
2
4
6
8
10
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{X}/\bar{L}_0$

Fig. C12

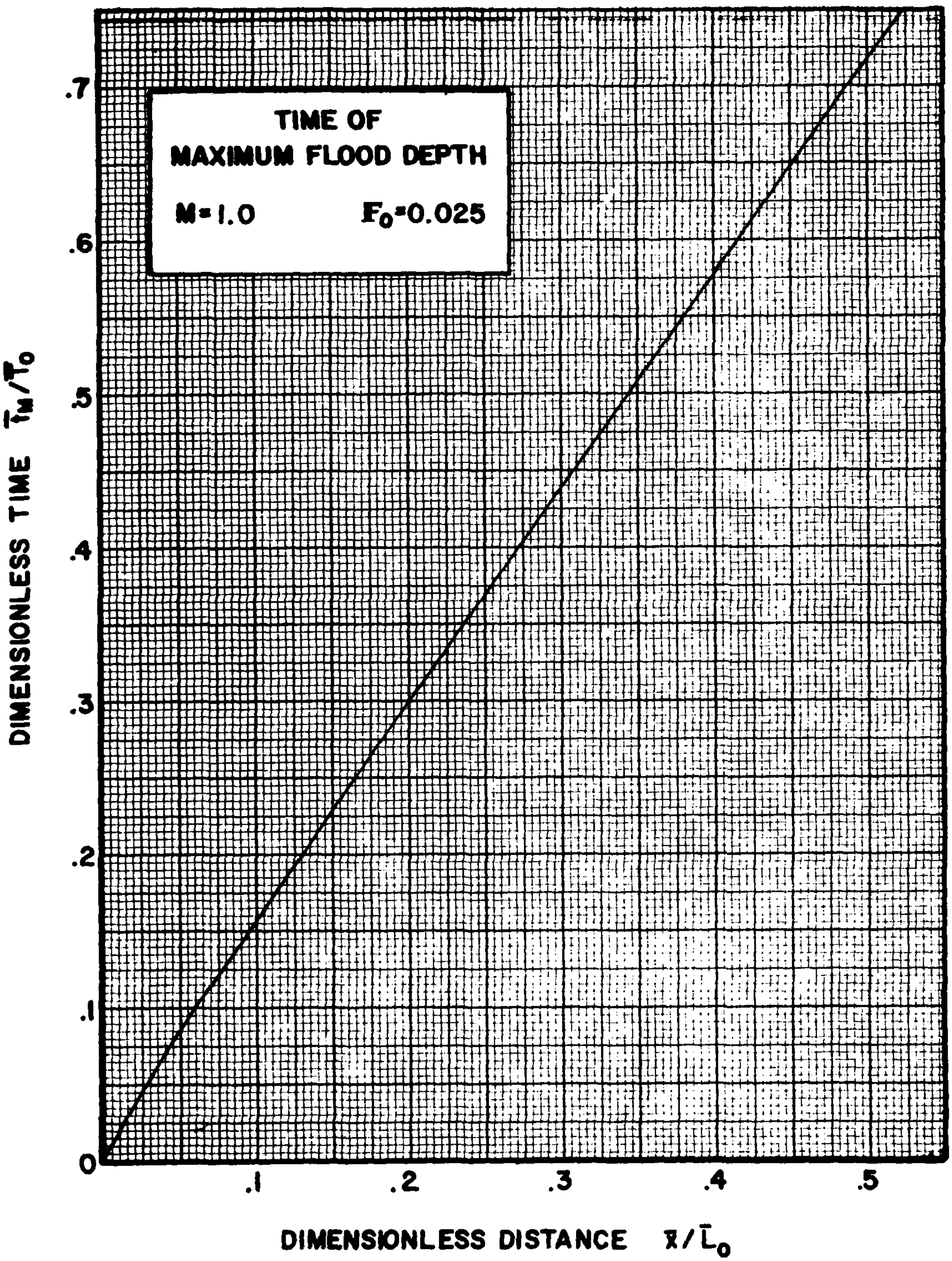

TIME OF
MAXIMUM FLOOD DEPTH
M=1.0
F0=0.025
.7
.6
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{X}/\bar{L}_0$

Fig. C13

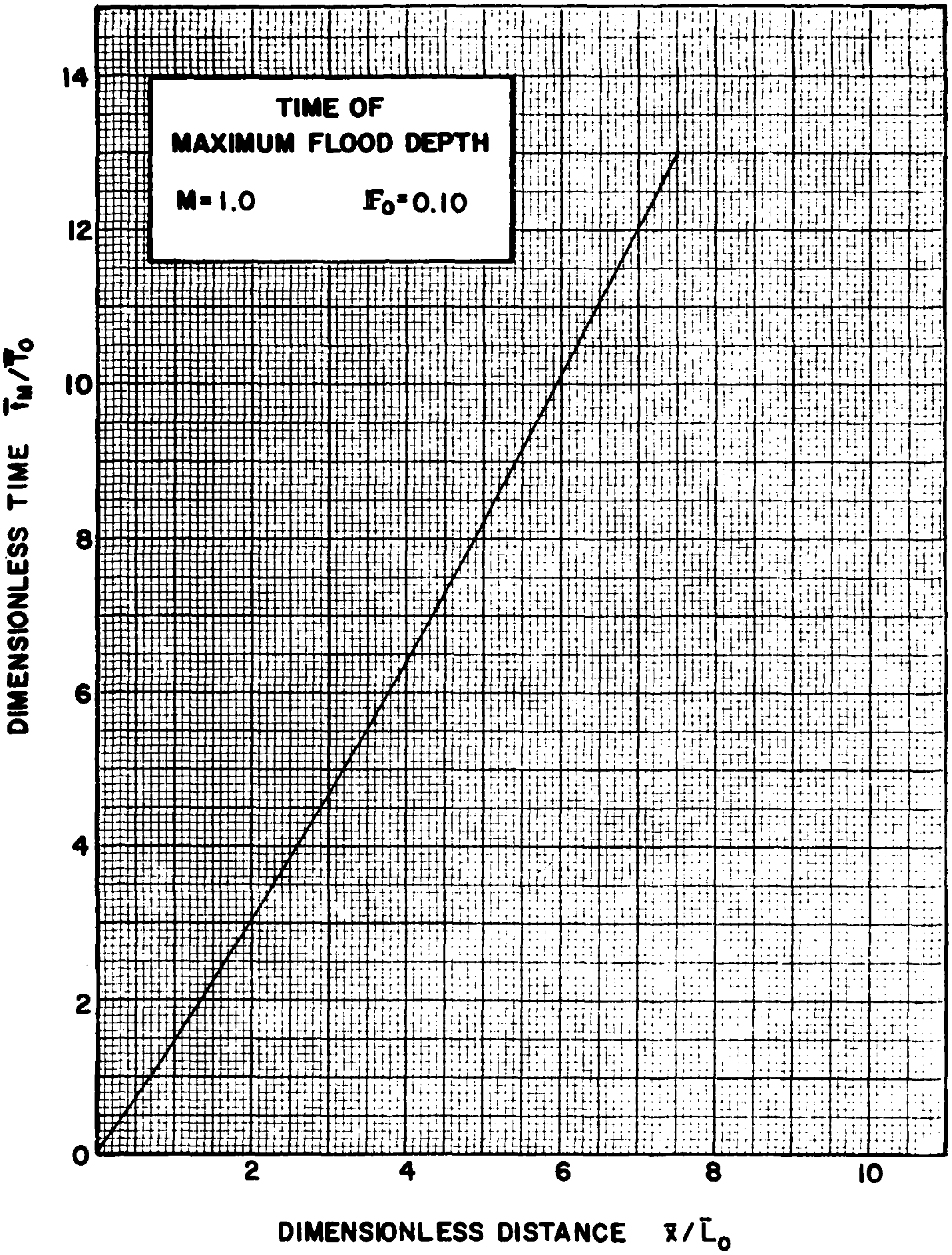

TIME OF
MAXIMUM FLOOD DEPTH
M=1.0
$\mathbb{F}_0$=0.10
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{x}/\bar{L}_0$
0
2
4
6
8
10
12
14

Fig. C14

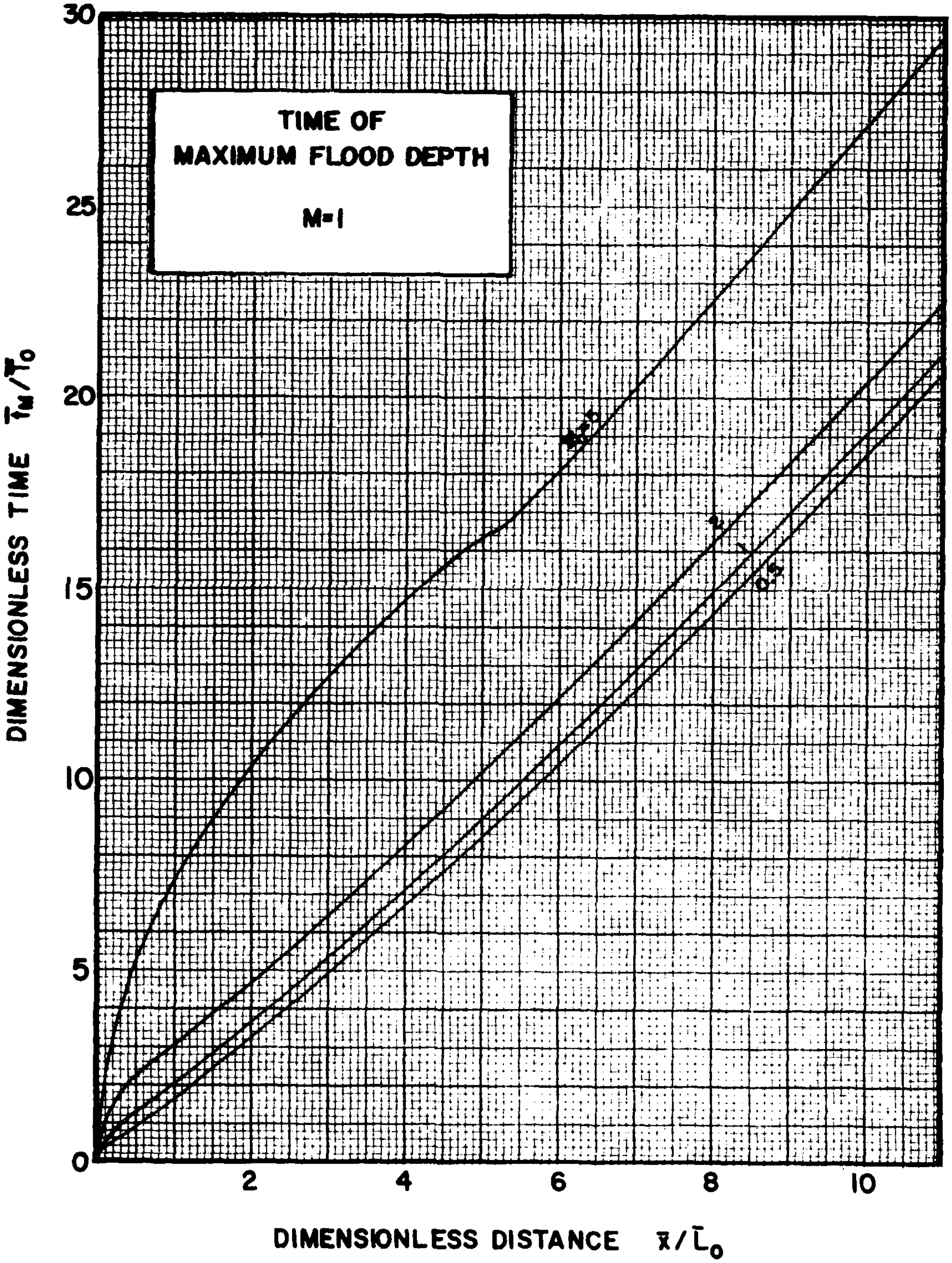

TIME OF
MAXIMUM FLOOD DEPTH
M=1
DIMENSIONLESS TIME $\bar{T}_M/\bar{T}_0$
DIMENSIONLESS DISTANCE $\bar{X}/\bar{L}_0$
0
5
10
15
20
25
30
2
4
6
8
10
2
1
0.5

Fig. C15

ANNEX I

Suggested Procedure for Developing a "Representative" Prismatic Channel

I-1. Introduction

Routing the dam break flood with these non-dimensional graphs is a three step process. The procedure in the main body of this report is the final step. It requires two previous steps as follows:

The irregular natural topography must be transformed into a "representative" prismatic channel

and

The coefficients that are required to express the resulting cross section shape, flow velocity, and flow depth must be non-dimensionalized.

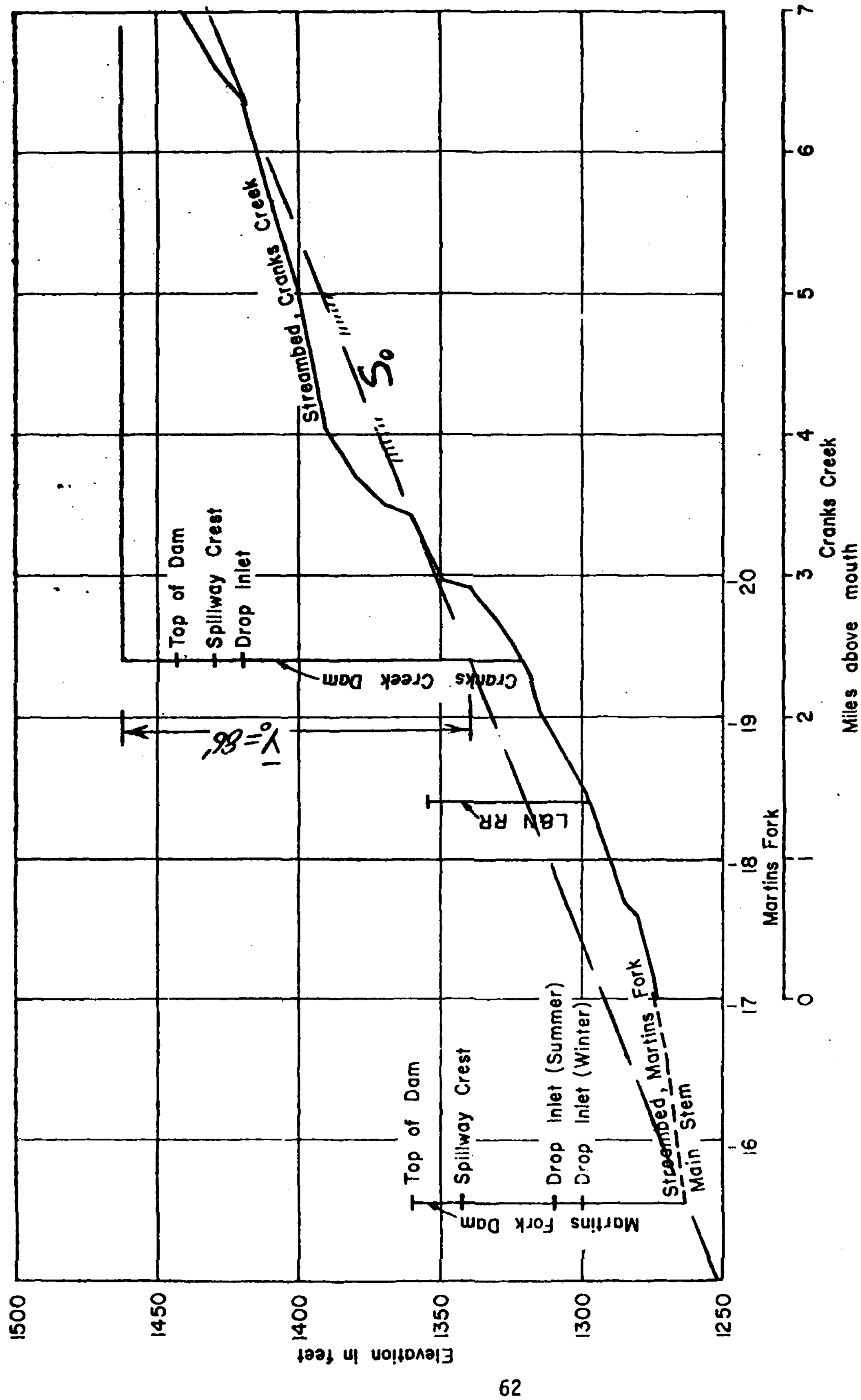
The following procedure is a suggestion for accomplishing these two steps. It is designed to preserve the potential energy slope, the head on the dam at failure, the reservoir volume, and the distance from the dam to the point of interest. Notation is the same as that used in the main body of the report.

I-2. Representative Stream Slope

Plot a stream bed profile from the upstream end of the reservoir to the downstream point of interest. Fit a single, straight line through the plotted profile in such a manner that the average potential energy gradient is maintained. This represents S_o as illustrated in Fig. I-1.

I-3. Representative Reservoir Length

Mark the location of the dam being analyzed on the stream bed profile and plot the reservoir elevation for conditions at the time of failure. Measure the head, Y_o, from the pool elevation to the channel bed elevation. Plot this head above the S_o profile.



Elevation in feet
1500
1450
1400
1350
1300
1250
Top of Dam
Spillway Crest
Drop Inlet
Cranks Creek Dam
Streambed, Cranks Creek
S_o
$Y_o = 86'$
L&N RR
Top of Dam
Spillway Crest
Drop Inlet (Summer)
Drop Inlet (Winter)
Martins Fork Dam
Streambed, Martins Fork
Main Stem
16
17
18
19
20
Martins Fork
0
1
2
3
4
5
6
7
Cranks Creek
Miles above mouth

Calculate $\bar{L}_0$ by dividing the head, $\bar{Y}_0$, by bottom slope, S_0. This distance represents the length of the reservoir.

I-4. Calculating the Representative Prismatic Cross Section

By idealizing the shape of the reservoir as approximating that of a pyramid, the volume may be calculated with the following equation.

$$Vol = (1/3) \cdot \bar{A} \cdot \bar{L} \qquad \text{(I-1)}$$

$\bar{A}$ = Cross sectional area at dam for depth $\bar{Y}$

$\bar{L}$ = Reservoir length for depth $\bar{Y}$ at the dam

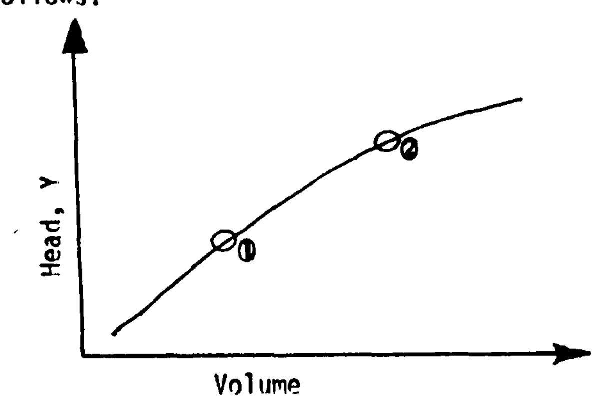
It is necessary to express cross sectional area in terms of the coefficients utilized in the main body of this report. Starting with equation (5), page 3, and integrating leads to the following

$$\bar{A} = \frac{\bar{C}}{M+1} \cdot \bar{Y}^{M+1} \qquad \text{(I-2)}$$

Since the $\bar{L}$ in equation I-1 may also be expressed in terms of $\bar{Y}$, the volume equation may be written as

$$Vol = \frac{\bar{C}}{3 \cdot (M+1) \cdot S_0} \cdot \bar{Y}^{M+2} \qquad \text{(I-3)}$$

This equation has one independent term, Y, and one dependent term, Vol. The slope parameter, S_0, is known, and the two coefficients $\bar{C}$ and M and the unknowns. By curve fitting through 2 points, two equations may be developed as follows.



at point 1;

$$Vol_1 = \frac{\bar{C}}{3 \cdot (M+1) \cdot S_0} \cdot \bar{Y}_1^{M+2} \qquad (I-4)$$

at point 2;

$$Vol_2 = \frac{\bar{C}}{3 \cdot (M+1) \cdot S_0} \cdot \bar{Y}_2^{M+2} \qquad (I-5)$$

Solving equations (I-4) and (I-5) yields

$$M = (\log(Vol_2/Vol_1)/\log(\bar{Y}_2/\bar{Y}_1)) - 2 \qquad (I-6)$$

$$\bar{C} = Vol_1 \cdot 3 \cdot (M+1) \cdot S_0/\bar{Y}_1^{M+2} \qquad (I-7)$$

Since M is dimensionless, any units may be used for Vol and for $\bar{Y}$ in equation (I-6). Equation (I-7) requires consistent units between Vol and $\bar{Y}$, however. The following example illustrates the use of equations (I-6) and (I-7).

Actually, any two arbitrary points may be selected for calculating $\bar{C}$ and M. However, in keeping with the objective of approximating the reservoir volume, the head on the dam at the time of failure is selected as one of the points and $\frac{4}{9}$ of that head is used for the other. These are converted to elevations and reservoir storages read from the elevation capacity curve as follows.

Table I-1. Data for Calculating Coefficients for the Prismatic Section

Point	Head (Ft)	Channel Elevation	Pool Elevation	Reservoir ac ft	Volume 10^6 cu ft
1	86	1323	1409	26572	1157.476
2	38	1323	1361	4134	180.077

Substituting these data into equations (I-6) and (I-7)

$M = (\text{Log}(4134/26572)/\text{Log}(38/86)) - 2.0$

$M = 0.278$

$\bar{C} = 180.077(10^6) \cdot 3 \cdot 1.278 \cdot 0.001/38^{2.278}$

$\bar{C} = 173.92$ ft

I-5. Calculating the Non-Dimensional Coefficients

The coefficient, $\bar{C}$, is non-dimensionalized by using the head on the dam at the time of failure, $\bar{Y}_0$.

$$C = \bar{C} \cdot \bar{Y}_0^{M-1} \tag{I-8}$$

$$= 173.92 \cdot 86^{0.278 - 1}$$

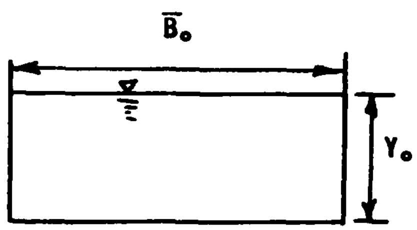
$$C = 6.98$$

The Froude number, F_0, is already non-dimensional. However, it must be calculated for conditions at the moment of failure. This requires the following equations.

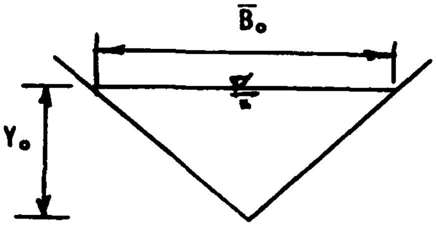
$$F_0 = \bar{V}_0/\sqrt{g \bar{Y}_0} \tag{I-9}$$

$$V_0 = \frac{1.486}{n} \bar{R}_0^{2/3} S_0^{1/2} \tag{I-10}$$

Calculating the hydraulic radius term in equation (I-10) is difficult since wetted perimeter is not known. The following interpolation scheme is proposed. When M = 0, the section is rectangular; when M = 1, it is a triangular section. Using the value calculated above for $\bar{C}$, calculate the hydraulic radii for M = 0 and for M = 1. Then interpolate, based on the true value of M, to obtain $\bar{R}_0$ as follows.



M=0



M=1.0

$\overline{A}_o = \overline{B}_o \cdot \overline{Y}_o$

$\overline{P}_o = \overline{B}_o + 2 \cdot \overline{Y}_o$

$\overline{A}_o = 1/2 \cdot \overline{B}_o \ \overline{Y}_o$

$\overline{P}_o = 2 \cdot \sqrt{(\overline{B}_o/2)^2 + \overline{Y}_o^{\,2}}$

Interpolate to obtain $\overline{R}_o$ for any M between 0 and 1

$$\overline{R}_o = (\overline{A}_o/\overline{P}_o)_{M=0} + M \cdot \left((\overline{A}_o/\overline{P}_o)_{M=1} - (\overline{A}_o/\overline{P}_o)_{M=0} \right)$$

Example: $M = 0.278$

$M = 0$:

$\overline{A}_o = 600 \cdot 86$

$\overline{P}_o = 600 + 2 \cdot 86$

$\overline{R}_o = 66.84$

$M = 1.0$

$\overline{A}_o = \frac{600 \cdot 86}{2}$

$\overline{P} = 2 \cdot \sqrt{(600/2)^2 + 86^2}$

$\overline{R}_o = 42.93$

$$\overline{R}_o = 66.84 + 0.278 \cdot (42.93 - 66.84)$$

$$\overline{R}_o = 60.19$$

With the hydraulic radius now determined, the dimensional velocity may be calculated from equation (I-10).

In this problem, S_o is equal to 0.001.

$$\bar{V}_o = \frac{1.486}{.07} \cdot 60^{2/3} \cdot 0.001^{1/2}$$

$$= 10.5 \text{ fps}$$

The Froude number is calculated with equation (I-9).

$$\mathsf{F}_o = 10.5/\sqrt{86g}$$

$$\mathsf{F}_o = 0.20$$

The required dimensionless parameters are completely determined and summarized below

$M = 0.278$

$\mathsf{F}_o = 0.20$

$C = 7$

The length term, L_o, used to nondimensionalize distance is calculated as

$$\bar{L}_o = \bar{Y}_o/S_o \qquad \text{(I-11)}$$

$$\bar{L}_o = 86/0.001 = 86{,}000 \text{ ft}$$

The time used to calculate dimensional time from the nondimensional routing curves is

$$\bar{T}_o = \bar{L}_o/\bar{V}_o$$

$$= 86{,}000/10.5$$

$$= 2.28$$

Tables 1, 2, and 3 in the main body of the report show the use of these dimensionaless parameters for routing a dam break flood. The calculated depth should be referred to the actual bed profile for expressing results in terms of elevation.